User's Guide to the SoDa and SOLEMI Services

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USER’S GUIDE TO THE SODA AND SOLEMI SERVICES
Towards the “solar energy radiation resources MACC-RAD Service”

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Executive Summary

The European Earth observation programme GMES (Global Monitoring for Environment and Security) aims at providing environmental information to support policymakers, public authorities and both public and commercial users. A systematic monitoring and forecasting of the state of the Earth's subsystems is currently under development. Six thematic areas are developed: marine, land, atmosphere, emergency, security and climate change. A land monitoring service, a marine monitoring service and an atmosphere monitoring service will contribute directly to the monitoring of climate change and to the assessment of mitigation and adaptation policies. Additional GMES services will address respectively emergency response and security-related aspects.

The pre-operational atmosphere service of GMES is currently provided through the FP7 project MACC (Monitoring Atmospheric Composition and Climate). MACC combines state-of-the-art atmospheric modelling with Earth observation data to provide information services covering European Air Quality, Global Atmospheric Composition, Climate, and UV and Solar Energy.

Within the radiation subproject (MACC-RAD) existing historical and daily updated databases for monitoring incoming surface solar irradiance are further developed. The service will meet the needs of European and national policy development and the requirements of (commercial) downstream services (e.g. planning, monitoring, efficiency improvements, integration into energy supply grids). The SOLEMI service (operated by MACC partner DLR) and the SoDa service (operated by MACC partner ARMINES and its subsidiary Transvalor) have been specifically developed in several national, European and ESA projects to fulfil the requirements for long-term databases and NRT services.

On its transition process from the precursor services SoDa and SOLEMI the following User's Guide intends to summarize existing knowledge, which has been published only in a scattered manner.

Part A 'Users' Expectations' describes the communities of users, their expectations and gives an overview of the compliance of the MACC RAD service with those.

In Part B 'Creating Databases', the current databases HelioClim and SOLEMI as well as the methods used to convert satellite images into solar surface irradiance are presented. The quality of the retrieved irradiances is discussed. An overview of the operations and workflow is presented for the creation, updating and monitoring of these databases.

Part C 'Delivering products' is devoted to the supply of products. The core products are defined. The future MACC-RAD Service is described and a prototype is presented.

It is intended to update this User's Guide regularly following the realisation of the MACC RAD service line.

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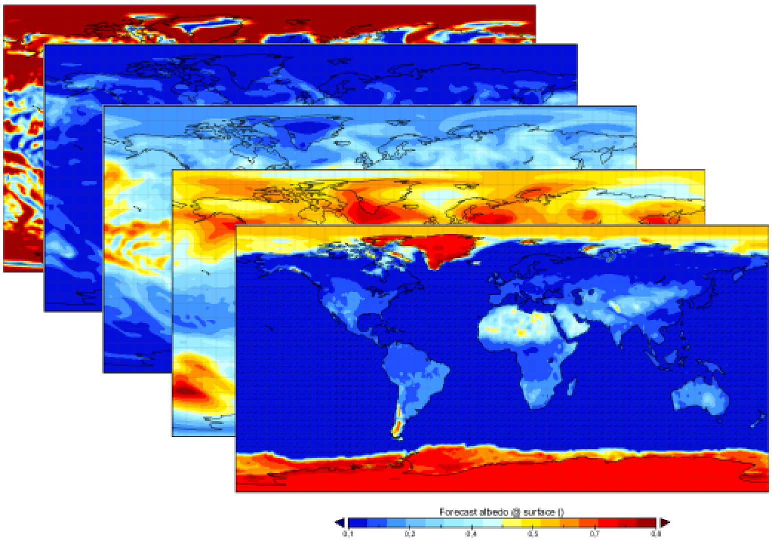
1. Introduction

The MACC (Monitoring Atmospheric Composition and Climate) project is designed to meet the requirements that have been expressed for the pilot GMES Atmospheric Core Service. The project has been prepared by the consortia of the EC-FP6 project GEMS and the ESA-GSE project PROMOTE, whose core service lines will provide the starting point for MACC. From mid-2009 MACC will continue, improve, extend, integrate and validate these service lines, so that the overall MACC system is ready near the end of 2011 for qualification as the operational GMES Atmospheric Core Service. MACC will prepare the core service in terms of implementation, sustained operation and availability. It will maintain and further develop the efficiency and resilience of the end-to-end pre-operational system, and will refine the scientific basis and quality of the products of the system. It will ensure that its service lines best meet both the requirements of downstream service providers and end users at the European, national and local levels, and the requirements of the global scientific user community.

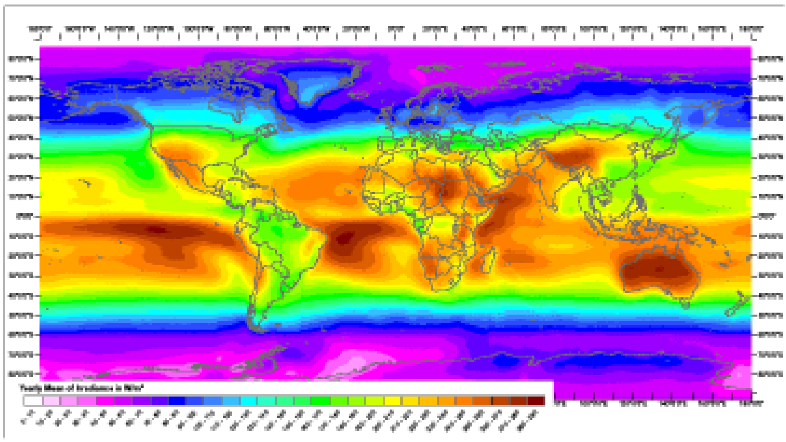
The service lines will cover air quality, climate forcing, stratospheric ozone and solar radiation. MACC will deliver operational products and information that support the establishment and implementation of European policy and wider international programmes. It will acquire and assimilate observational data to provide sustained real-time and retrospective global monitoring of greenhouse gases, aerosols and reactive gases such as troposphere ozone and nitrogen dioxide. It will provide daily global forecasts of atmospheric composition, detailed air-quality forecasts and assessments for Europe, and key information on long range transport of atmospheric pollutants. It will provide comprehensive web-based graphical products and gridded data on which downstream services may be based. Feedback will be given to space agencies and providers of in-situ data on the quality of their data and on future observational requirements.

One of the core services in MACC will provide radiation values at the ground level, which will fulfil the needs in European and national policy developments and the requirements of partly commercial downstream services, e.g., for planning, monitoring, efficiency improvements, and the integration of solar energy systems into energy supply grids.



To do so, several data originating from various sources are assembled. Many of them describe the optical state of the atmosphere, e.g., aerosol optical properties, water vapour and ozone contents over the atmospheric column. Others depict the ground properties, e.g., ground albedo, ground elevation.

These data are inputs to a model that simulates the scattering and absorption phenomena occurring in the atmosphere and affecting the solar radiation in its way downwards to the ground. The outputs of this model are values of the solar radiation available at ground level that can be used to produce energy, either as heat or electricity.



1.1. Objectives of the document

For the sake of simplicity, we denote by "MACC-RAD Service" the future service within the GAS (GMES Atmospheric Service) that will deliver core products on solar energy radiation resources.

The objectives of this document are to do document and specify this MACC-RAD Service as well as the user-access procedures to the products delivered by this service.

Actually, such a service is an information system composed of two major blocks. One is made of databases, processing chains, daily operations, methods, input data, control and monitoring of operations and quality of products. The other deals with the dissemination of the products, the means of access, control of dissemination and quality of service.

This report will document both blocks. As a service aims at satisfying needs of its users, the specifications of this service must be built on the description of the users expectations on products and delivery, and therefore of their profiles. The first part of this document (Part A) is therefore the description of the users and their expectations. Part B deals with the description of the databases, of the algorithms, of the operations towards the creation / update of the databases, validation process, monitoring. Part C deals with the delivery of products.

This document intends to be a living one. It will evolve as the service and its components themselves evolve in the transition process from the precursor services to the MACC-RAD Service.

1.2. Precursor services

Before proceeding, it is worth mentioning two precursor services which are the foundations of the MACC-RAD Service: the SoDa Service and SOLEMI Service, that are presently fully operational and managed by Armines and DLR. There is a variety of documentation, validation and user information available for both services – either from standard operations, from recent project related work or from international benchmarking exercises. Therefore, another objective of this user's guide is to combine and summarize this scattered information.

The SoDa Service originates from a EC-funded project (IST, 200-2003); it turned operational in 2003. Its number of customers increases regularly. From 400 users in 2003, it reached 42 000 users in 2009, and answered approximately 400 000 requests for data in 2009. The

SoDa Service is actually a portal and more exactly a collaborative information system. This means that by connecting to the SoDa Service, the user can access several services offered by several providers in a transparent and homogeneous manner. A service can be a data set, a database or an application. There are presently eleven providers for approximately 60 services. The SoDa Service is formally a means for disseminating knowledge. However, it is becoming so popular that its users often confuse the services offered by the SoDa Service into a single name: SoDa. Behind the SoDa Service, and among the various services offered, a major service is the access to the databases HelioClim of solar radiation at ground level. These databases, HelioClim-1 and -3, are created and managed by Armines. A routine exploitation of Meteosat images received by Armines provides 15-min values of radiation that are stored in the databases. Control of operations is performed automatically. Quality of products is checked regularly. In 2006, access to the most recent parts of the HelioClim database became for-pay. There is a few tens of customers for-pay of the SoDa Service. They are companies having themselves their own customers and own requirements and contingencies. The number of customers is increasing as well as their exigencies regarding the quality of service. Because Armines is a research institute, it does not have the necessary means and knowledge to handle a commercial service and to ensure and secure operations. In 2009, the company Transvalor, a daughter company of Armines, took over the control of the SoDa Service in order to enhance the safety in provision of data and to better handle customers. Presently, the operational processing chain converting Meteosat images into radiation values is implemented at Transvalor's premises to increase reliability in the timely provision of radiation data to customers, while the chain at Armines is now efficiently working as a back-up.

The SOLEMI Service has various properties that differ from the SoDa Service. Nevertheless, it is similar in principle to SoDa in the sense that it is a service: there is one series of actions to construct the database SOLEMI and a series of actions to exploit it for the benefit of customers. The properties of the database SOLEMI are described in the following pages. A series of efforts is underway to ease the access to the database, another series deals with the increase in quality of the irradiation values. The customers of the SOLEMI Service request more studies while SoDa customers require more irradiation data. Therefore, there is no need for the SOLEMI Service to offer access via the web like the SoDa Service. However, a service delivering part of the SOLEMI database has been developed by DLR and exposed in the prototype of the second generation of the SoDa Service (project.mesor.net).

For the sake of simplicity, this document treats both SOLEMI and SoDa Services in the same way, as if both were a collaborative information system.

One may see the SOLEMI and SoDA Services as concurrent services. This is true in many aspects. However, Armines and DLR share the same objective: performing research to open-up opportunities for companies. Armines and DLR are not competing on market grounds and have signed a legal agreement in 2008, binding Armines, DLR and Transvalor for the sales of next generation radiation products. This agreement is one of the essential pillars of the proposed MACC-RAD Service.

1.3. Acronyms and definitions

DirHI	Direct Irradiance, or Irradiation. Part of the radiation that is received from the direction of the sun on a horizontal plane.
DifHI	Diffuse Irradiance, or Irradiation. Part of the radiation that is received on a horizontal plane from all directions except that of the sun.
DNI	Direct Normal Irradiance, or Irradiation. Part of the radiation that is received from the direction of the sun by a plane facing the sun.

GAS	GMES Atmospheric Service
GHI	Global Horizontal Irradiance, or Irradiation. The radiation that is received by a horizontal plane from all directions.
HelioClim	A set of databases on solar radiation available at ground level, created by Armines from Meteosat images. HelioClim-1 covers the period 1985-2005, HelioClim-3 starts in 2004 and is on-going.
Heliosat	Name of a family of methods to convert images acquired by meteorological geostationary satellites into images of solar radiation available at ground level. For example, the data bases HelioClim-1 and -3 are constructed with the method Heliosat-2.
IEA	International Energy Agency
MACC	Monitoring Atmosphere Composition and Climate. An EC-funded research project to establish the GMES Atmospheric Service.
MACC-RAD	A sub-project within MACC dealing with radiation.
MACC-RAD Service	The core service within the GAS that delivers core products on solar radiation at ground level.
SoDa Service	A Web portal offering an one-stop access to several services (databases, applications) relating to solar radiation.
SOLEMI	Solar Energy Mining. It corresponds to both method and service providing SSI.
SSI	Surface Solar Irradiance, also called surface downward solar irradiance, or surface downward shortwave irradiance. It can also denotes irradiation, which is the irradiance multiplied by a duration. For example, hourly irradiation is equal to the hourly average of irradiance multiplied by 3600 s.

PART A. USERS' EXPECTATIONS

2. Communities of users

Who are the expected users of the MACC-RAD Service? To best design the information system, we need to know who are the users, their typology, how do they structure in communities and domains, and for which purposes they are using the SSI data.

Relationships between users and development of information systems providing SSI are long-standing ones. There are well-established communities of users such as

- planners and managers of solar energy systems and power plants,
- architects and building engineers,
- researchers in renewable energies and building engineering.

There are more and the situation is evolving. New communities of users are attracted by the availability of irradiance data, because they are new in renewable energies such as local authorities and municipalities, or they are in a new domain of activity, e.g., material weathering and ageing.

The managers of the existing information systems delivering SSI such as SOLEMI and SoDa Service and other providers are regularly performing surveys in order to better know their users and establish typologies to improve answers to needs.

Regarding the use of SSI for energy production and building engineering, several recent surveys and outcomes of international initiatives are of interest:

- MESoR (Management and exploitation of solar resource knowledge), funded by the EC DG-TREN, 2007-2009 (www.mesor.org) (Hoyer-Klick et al. 2008, 2009),
- EnviSolar (Environmental information services for solar energy industries), funded by the European Space Agency, 2004-2006 (www.envisolar.com) (Schroedter-Homscheidt et al. 2006),
- GEOSS Energy Community of Practice (www.geoss-ecp.org),
- the Energy Chapter in the 2007 GEO report *The Full Picture* (Schroedter-Homscheidt et al. 2007),
- SWERA (Solar and wind energy resource assessment), a programme of UNEP, 2004-2008 (swera.unep.net),
- IEA SHC 36. International Energy Agency, Solar Heating and Cooling Implementing Agreement, Task 36, 2005-2010 (www.iea-shc.org/task36) (Huld et al. 2008).

A first typology of users can be found from these surveys:

- companies (engineering bureaus, energy producers, investors, plant managers, maintenance services and electricity grid managers),
- experts (engineering bureaus, private R&D),
- public research institutes (engineering bureaus, private R&D),
- public authorities and other organisations supporting policy making, incentives and permit delivery at national, regional or local levels, as well as European policy makers in charge of supporting the implementation of EU policies.

The present work aims at better defining this typology of users, what are their domains of application (or discipline or field), and what are their purposes in using data. It is based on the exploitation of several recent surveys, described in Table 2.1, and of the knowledge gained in the exploitation for several years of services supplying SSI to users or in the above-mentioned projects.

Name	Date	Number of respondents	Comments
IEA SHC 36	2007	111	Respondents were not selected. The questionnaire was on-line on several web sites
SoDa 2005	2005	159	Respondents were not selected. The questionnaire was on-line on the Web SoDa Service

Table 2.1. List of surveys used in the present work

Figure 2.1 exhibits the typology of users and their relative importance as reported by SHC 36 and the SoDa Service. Questions were not exactly the same in both surveys. It is possible that several users are misplaced between "companies" and "engineering bureaus". Nevertheless, both surveys clearly show the importance of the private sector: approximately two-thirds of the users belong to this sector.

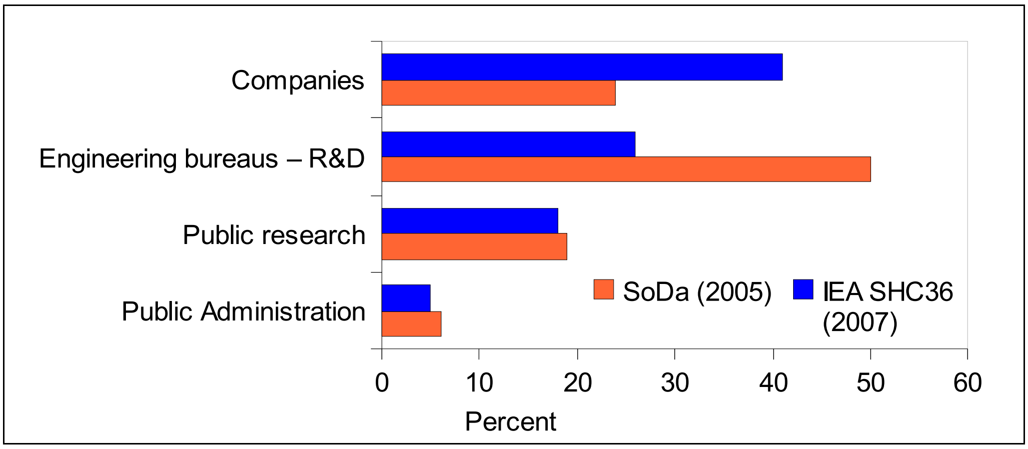


Figure 2.1. Typology of users and their relative importance

There are several purposes in the use of data. Their list and their relative importance are presented in Figure 2.2.

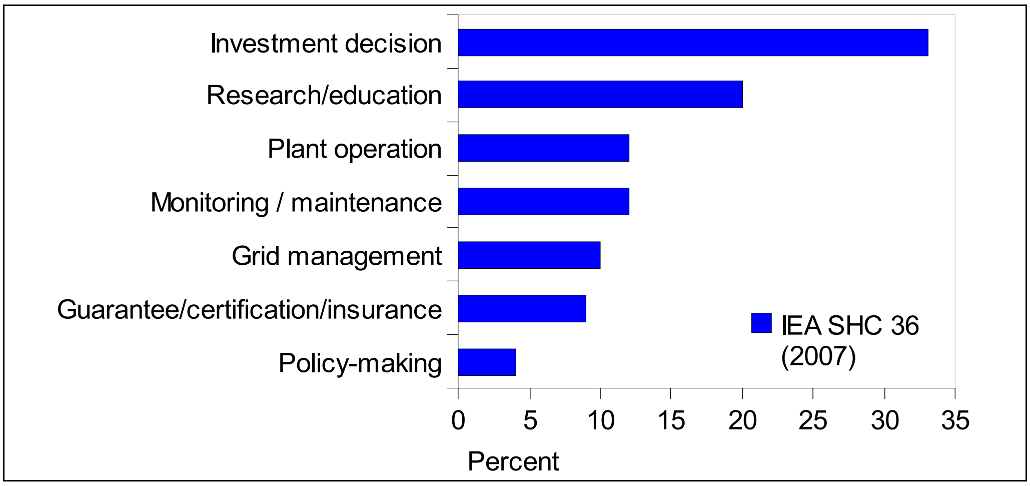


Figure 2.2. List of purposes for use of SSI data and their relative importance

The most important purposes are related to the investment decision: system design, feasibility study, cost assessment, and site selection. SSI data are often used for research and education as already shown in Figure 2.1. Plant operation and monitoring are getting more and more importance as the number of plants is increasing. Smaller solar energy systems need low cost monitoring with a performance check while large solar energy systems need detailed monitoring with automatic fault detection routines. Certification and guarantee are attractive features to customers of the energy suppliers and installers of power systems. Electric power transmission systems collect power from the conventional plants as well as from different renewable sources like solar PV plants. Two major aspects for the management of such a complex grid system to ensure the quality of the supply in electricity is an accurate forecast of the solar power generated and of the expected demand, and a good knowledge of past events and their probabilities.

Finally, policy-making has a limited importance in the request for SSI data. An increase is expected as the local authorities and municipalities are more and more orientated towards sustainability for which exploitation of renewable energy is an important issue.

The survey made by the SoDa Service provides an insight of the various domains of activities of its users and their relative importance in the total number of requests for SSI (figure 2.3). Several answers were possible for each respondent.

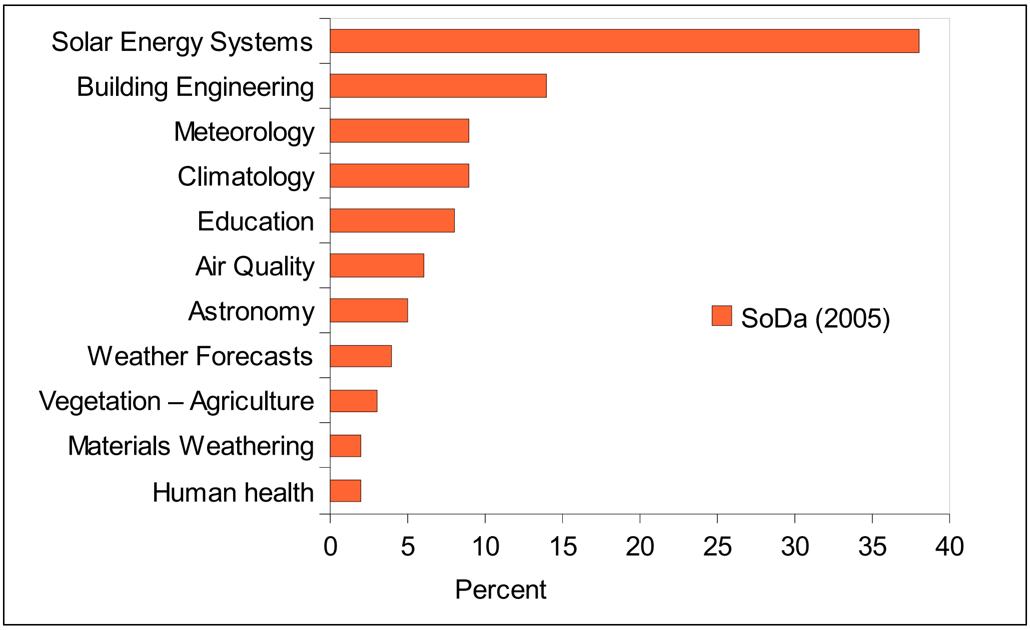


Figure 2.3. Domains of activities of the users of the SoDa Service and their relative importance

Users exploit the SoDa Service in relation with activities in production of energy (38%) and building engineering (15%). These domains represent more than half of the answers (53%). For companies, figures are much larger: production of energy (46%) and building engineering (20%). For companies, these domains represent two-thirds of the answers (66%).

The other half of answers spread themselves in meteorology and climatology (10% each), air quality (urban pollution, radiative budget), astronomy (position of the sun relative to the observer), weather forecasts (SSI, cloud cover), vegetation and agriculture (SSI, PAR), materials weathering and ageing, and human health (skin cancer, eye diseases, multisclerosis). Education is an important activity for the users of the SoDa Service (10%).

One concludes that the SoDa Service is well used by the community in production of energy and building engineering, and also by other communities. It is believed that its usages and users: typology and structure, are representative of what could happened with the MACC-RAD Service.

3. Users' expectations

Users' expectations have been assessed by several surveys and projects with respect to the parameters to be delivered and temporal and spatial resolution. A few dealt with the concept of service as a whole such as the project ENVISOLAR (Schroedter-Homscheidt et al. 2006) and those funded by the IEA (Cros, Wald 2003; Cros et al. 2004; Wald 2006).

We exploit this mass of information together with two recent relevant surveys: IEA SHC 36 and MESoR (Table 3.1). The IEA SHC 36 survey has been presented in the previous Chapter. The MESoR survey differs in several aspects. The sample of 30 respondents was selected by the MESoR consortium according to criteria of importance of data and frequency of usage as well as attitude to scientific cooperation. The surveyed organisations are active in the fields of solar energy systems and building engineering. They are located in various European countries plus the USA. The interviews by phone aimed at collecting information and evaluation about requirements, including needs for data (parameters, format, quality, resolution, etc.), service provision (coverage, availability), as well as about the attitude and interest towards the integration of the existing services into a unique point of access.

In addition, as it has been found that the usages and users of the SoDa Service are representative of what could happened with the MACC-RAD Service, we have exploited several findings on the usage of the SoDa Service in years 2008 and 2009 (Table 3.1).

Name	*Date*	*Number of questionnaires*	*Comments*
IEA SHC 36	2007	111	Users were not selected. The questionnaire was on-line on several web sites
MESoR	2008	30	Users were selected and interviewed on the phone
SoDa	2008 or 2009	Based on several thousands of requests	It is not a survey filled in by users but a survey of the use of data provided by the SoDa Service during periods spanning one or more years

Table 3.1. List of surveys and findings used in the present work

The core products of the MACC-RAD Service will be exploited by commercial users to produce their own services dedicated to their own customers (downstream services). We rely on the experience gained by the present SOLEMI and SoDa Services to obtain the business-related users' expectations.

Users expectations are treated in several categories:

- *data*: which data are expected, which geophysical parameters,
- *metadata and ancillary information*: which other data are useful to exploit the main data,
- *access to data*: how can users practically access data, and which format,
- *documentation*: which documentation is expected,
- *quality of service*: operations, help desk, customers desk, data policy,
- *monitoring quality*: scientific validation of products, quality in delivery.

3.1. Data

3.1.1. Geophysical parameters

Figure 3.1 lists the geophysical parameters requested by the users and their relative importance according to the surveys IEA SHC 36 and MESoR.

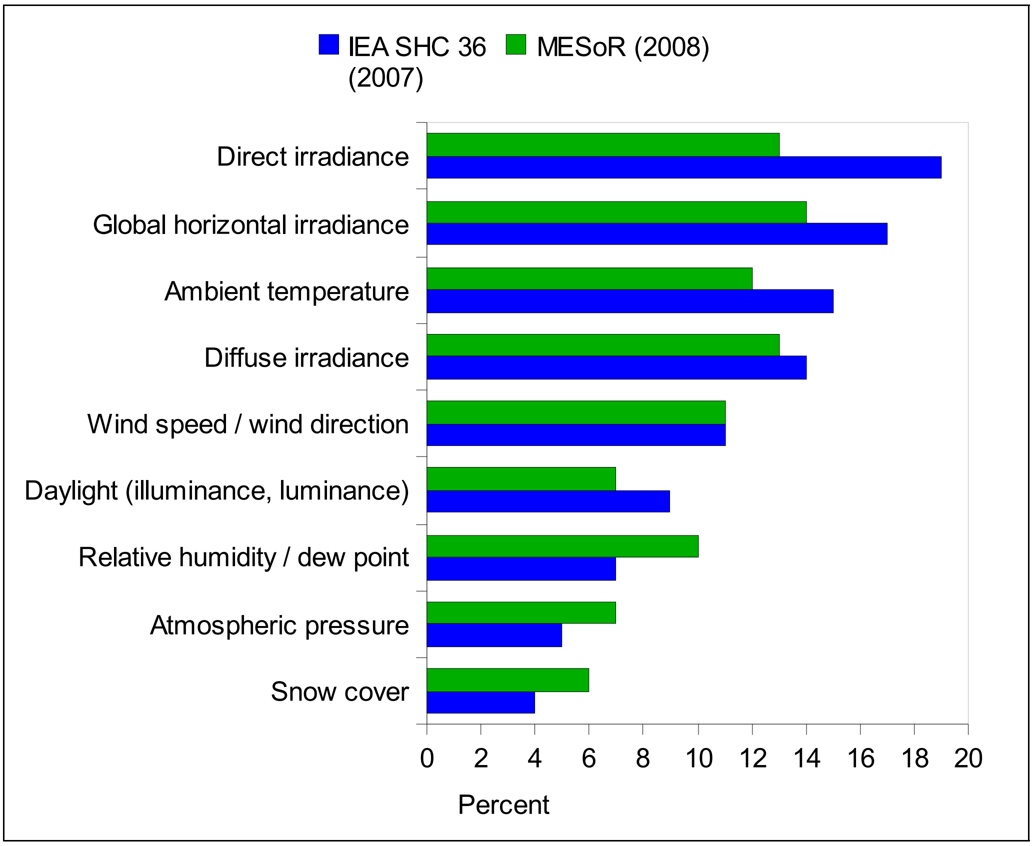


Figure 3.1. Geophysical parameters requested and their relative importance

Results differ slightly by a few percents from one survey to another. This may be explained by the diversity in panels and by the content of the questionnaires. Nevertheless, both agree on the importance of global, direct and diffuse irradiances (GHI, DirHI, DifHI).

The demand for ambient temperature, or air temperature at 2 m height, is high. Actually, there is a request for having auxiliary meteorological data at the surface: air temperature, wind speed and direction, relative humidity and atmospheric pressure, which are coincident with irradiance data. These data are useful for computing the radiative budget of the solar energy system, thus having a more accurate assessment of the gains and therefore of the energy production. This is also true in building engineering to compute gains and losses in heat of buildings.

Unsurprisingly, users in building engineering request data in illuminance as this is the parameter used in daylighting in building.

A few users ask for snow cover. Snow may cover panels, thus reducing the energy production. It may also be confused with clouds by methods assessing the SSI from satellite images; its knowledge increases the reliability of the SSI data.

3.1.2. Spatial and temporal resolutions

According to these surveys, the spatial resolution of the data ranges clearly from 5 to 10 km, though there is marked interest for higher resolution of 1 km.

Figure 3.2 exhibits the list of temporal resolutions requested by users and their relative importance. Numbers differ slightly between both surveys but are in agreement. Both show that monthly values of SSI attract the greatest attention, followed by hourly values. The demand for daily values is the lowest.

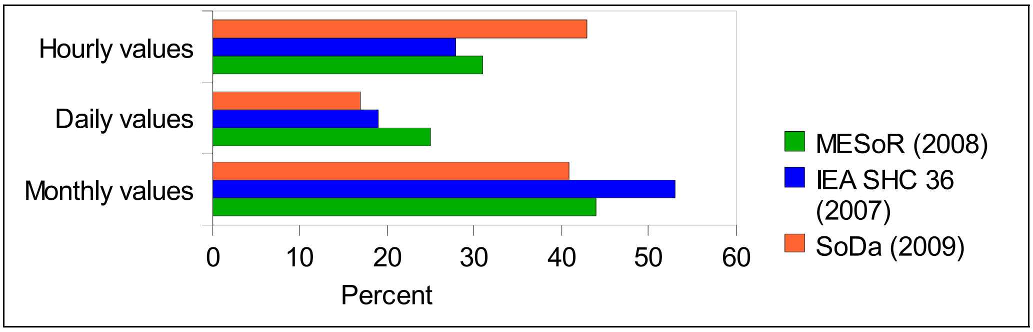


Figure 3.2. Temporal resolutions requested and their relative importance

We add on this graph findings from the usage of the SoDa Service. During 2009, SSI data for the year 2005 were for free independently of the temporal resolutions. Computing the number of requests made for each resolution relative to the total number of requests provides a clear view of the most requested temporal resolutions.

The demand for daily values is small, in agreement with the surveys. For hourly and monthly values, the results are somehow conflicting. There were much more requests to hourly values than expected and slightly less for monthly values. The discrepancy between the expressed expectations and the effective behaviour of the users may be explained by the time lag between the surveys and the findings from the SoDa Service. At the time of the surveys (2007 and 2008), hourly data were not easily accessible. We believe that making them freely available in an easy manner creates a change in the usages of data.

It could be reported here that there has been an explosion of the number of requests for hourly values made to the SoDa Service in 2010 due to the increasing use of such SSI data for monitoring solar power plants.

3.1.3. Time-series or maps

Most data sources deliver data in the form of time-series. Users expressed differently in surveys when asked about their preferences for time-series of data (1 or more sites) or maps (i.e. gridded values). According to IEA SHC 36, both types seem useful to respondents. In the MESoR survey, users prefer clearly time-series to maps.

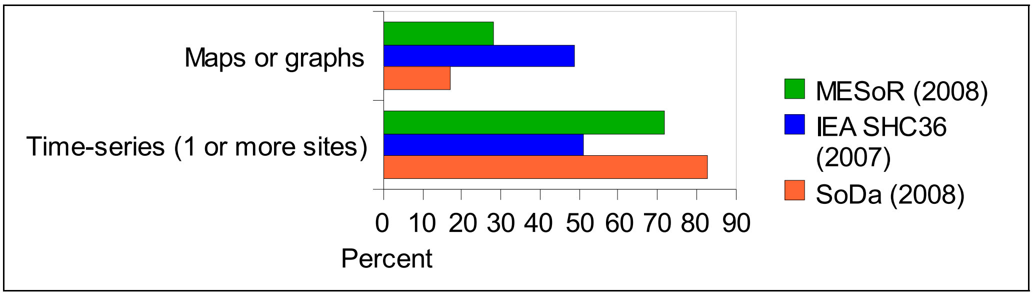


Figure 3.3. Percentage of users preferring time-series or maps

We add on this graph findings from the usage of the SoDa Service. During 2008, a mapping capability was made available for monthly values. Computing the number of requests made for maps relative to the total number of requests provides a view of the relative importance of maps. There are much more requests for time-series than for maps. Clearly, a provider of data should put priority on the capability of delivering time-series.

3.2. Metadata and ancillary information

Several pieces of additional information should be delivered with SSI data, besides the meteorological data mentioned above. These are metadata and ancillary information.

Metadata provide description of the data, e.g., date and time, geographical coverage, etc. They are necessary to exploit the data. There are two types of metadata.

One type is for discovery. It describes the data that could be delivered by a service, the list of products and how to obtain them. This type is exploited by catalogues of services and data. Examples are geographical or temporal coverage, spatial or temporal resolution, parameters.

The second type is for exploitation of data by computers or not. It describes the exact content of the supplied file containing the requested data. Examples are geographical location, elevation, parameters, instants.

It is recommended to use standard metadata such as those proposed by INSPIRE, GEOSS, and ISO.

Figure 3.4 demonstrates the importance of the metadata for exploitation. It displays the percentage of users using the supplied SSI data as inputs to a simulator and more generally to an application, or using SSI data directly in their work. This percentage is large. It means that provided the metadata supplied and those understood by the application share the same format, delivering exploitation metadata should ease the workload of the users.

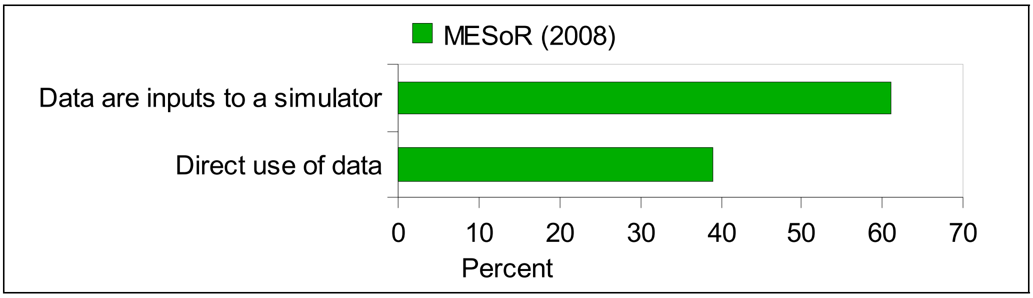


Figure 3.4. Percentage of users using the SSI data as inputs to an application

Users gather many different aspects in the term "ancillary information", such as:

- request for having as outputs in addition to SSI the data input to the method for SSI assessment, such as aerosol properties, water and ozone column content, etc.,
- say whether data are interpolated or not in space or time,
- reliability, i.e., one or more quantities stating whether the supplied data, as a whole or individually, are reliable,
- uncertainties, i.e., one or more quantities about the accuracy of the supplied data, as a whole or individually.

3.3. Access to data

Access to data covers several aspects: where, when, how. As a whole, users desire to access to data for anywhere and anytime; they desire to have an easy and fast access to these data whenever they want, from anywhere.

The geographical coverage requested by users depends strongly of their area of interest. For European users, emphasis is on Europe and Mediterranean basin. Ideally, the whole world should be covered.
The temporal coverage should span over several years, typically 10 or 15 recent years. Figure 3.5 displays the answers of respondents about the age of the SSI data.

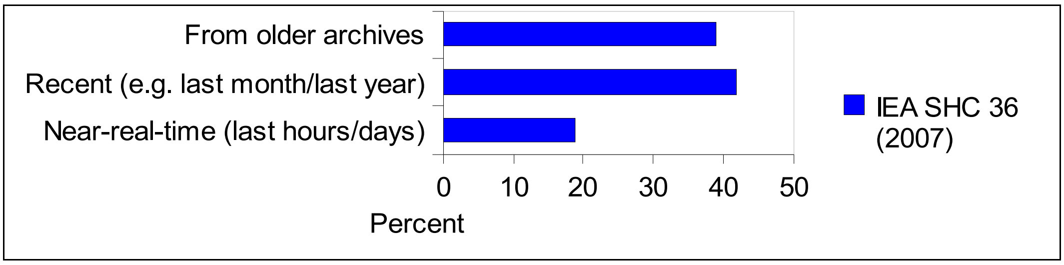


Figure 3.5. How recent should be the data

There is an equal spread of answers between archives and recent data (last month). Requests for very recent data are weak. The latter may have evolved in recent years due to the increase in monitoring activities of solar power plants, as discussed in section 3.1.

In the MESoR survey, all respondents underlined the importance of the Web as a mean to deliver information. They believed that accessing to the data by the Web makes things easier and faster, and because it would not be necessary to store information and applications in own information systems, thus reducing the burden in ICT expertise and hardware.

The Web has several advantages for users:
- it could be a one-stop shop to access various data,
- it can be accessed anytime from anywhere,
- a standard browser (e.g., Internet Explorer, or Firefox) can access the Web,
- the delivery of data can be instantaneous or so.

Finally, there is a large consensus in surveys about format of data. Users do not request for a specific format but do request for a standard type of file, namely text files (e.g., CSV files), or Excel-like spreadsheets. This is in line with the graph (Fig. 3.4) showing that products are further ingested into applications. As discussed earlier, these files should contain metadata describing the content of a file.

3.4. Documentation

Surveys reveal a great demand on documentation. Actually, there are several types of documentations requested:

- scientific documentation,
- service documentation,
- list of products and catalogue,
- data policy.

The scientific documentation comprises at best, the articles that support the methods and operations used to supply the products. These articles have been published in international peer-reviewed journals and are freely available on-line.

A report may be available that describes how the contents of these articles have been exploited to produce the SSI and other data. The respondents stressed the need for clarity and transparency about the procedures and methods.

The service documentation comprises the users' guide, describes operations, the workflow, and the various monitoring elements for quality assurance. Several procedures are described such as those used to fill gaps (spatial or temporal), or to flag and possibly remove erroneous data in temporally averaged products. The assessment of the reliability and the uncertainties of the data should be clearly depicted.

The list of products should be available, clear and comprehensive. A catalogue could be established with search capabilities.

Finally, data policy and intellectual property rights should be available and easy to read.

3.5. Quality of service

Users expressed concerns about the quality of service as a whole. By this, they expressed their expectations for a reliable service, working well, with no problem at all, and supplying what is expected.

Several users believe that such a service will work only if it can deliver products to users building their own services on the core products (downstream services). Accordingly, this service should work as a service to customers with customers' desk and helpdesk. The customers' desk deals with the commercial aspects of requests if any. The helpdesk helps in the use of the service.

The service should clearly express the means of delivery of the products and the time schedule. It should supply products in due course and punctually. If the Web is used to deliver, whether through a browser or e-mail, the delivery should be made in the moments following the order.

The SoDa Service offers capability to access data in an automated way by computers at a fixed hour every day. This capability should be offered in the MACC-RAD Service and enhanced. As several commercial applications are based on such capability, especially for monitoring solar power plants, supply of products should be safe. The Service should clearly indicate how it handles the various possible breakdowns and the ways to mitigate their consequences.

3.6. Monitoring quality

Users expressed concerns about the means for controlling the quality of the products. More precisely, questions arise about:

- the scientific quality. How it is established? What is the scientific validation of products? How often such a validation is made? How is it monitored?
- the quality of the workflow, i.e., monitor the smooth running of each operation and of the chaining. How is it made and how often? What are the plans to improve the method / workflow if scientific improvements are available?
- the quality of the service. How is it monitored and how often? How does it include surveys of incidents, concerns of users?

4. Answering the expectations

The MACC-RAD Service is designed in such a way that it satisfies the users' expectations as a whole. Each element is designed in view of its integration in a more complete system and not individually. The use of Web technologies and more generally, of GEOSS standards and best practices in exchange of data and interoperability of applications permits to design an efficient information system in a modular way. The concept of a collaborative information system on the Web adopted in the MACC-RAD Service is discussed at the end of this document. Best designed for its integration in the MACC-RAD Service, each element can be updated and improved without re-designing the whole information system.

The concept of the MACC-RAD Service is based on the following elements:

- operations and procedures to create databases of SSI, monitor the workflow, and control the quality,
- databases of SSI and other parameters. These databases contain basic information from which core products are created,
- applications that exploit these databases in order to create MACC-RAD core products. These applications are here Web services, i.e., applications that can be invoked on the Web,
- exposition of these Web services in a community repository (community portal) for their exploitation,
- a dedicated information system that interacts with the users, presents products, exploit the Web services to obtain products that it delivers to the users.

These elements are discussed in the next Chapters.

Prior to detailing these elements, we discuss the compliance of the proposed design to users' expectations. To that goal, we list the expectations and show whether the future MACC-RAD Service bring an appropriate answer or not to each of them. In order to show improvements with current situation, we do the same for the present services: SOLEMI and SoDa. In addition, we also compare to the planned transition system that is based on the well-known SoDa Service. This transition system will be set up in order to bring answers more rapidly, as the creation of the MACC-RAD Service is a lengthy task.

4.1. Data

Table 4.1 shows the compliance of the present services, the transition service, and the first and second versions of the MACC-RAD Service with respect to users' expectations on geophysical parameters.

The present services SoDa and SOLEMI deliver values for the global irradiance and its direct and diffuse components. These parameters will be delivered in the forthcoming services. Illuminance will be derived from total irradiance in the transition service, and will be directly computed in the MACC-RAD Service.

Request	Irradiance, illuminance	Snow cover	Other meteorological parameters
Present services	Yes - No	No	No
Transition Service	Yes - Yes	Yes, partly	No
MACC-RAD v1	Yes - Yes	Yes	Yes
MACC-RAD v2	Yes - Yes	Yes	Yes

Table 4.1. Compliance with the users' expectations regarding geophysical parameters

Snow cover is not a parameter delivered by the present services. It will be considered in the transition service, at least as a flag indicating a possible lack of reliability of the SSI estimate. Further versions will both take into account snow cover in the SSI estimates and provide snow cover parameter.

Other meteorological parameters are not delivered by the present services. They will not either in the transition service. The MACC-RAD Service will provide them.

Table 4.2 shows the compliance of the services with respect to users' expectations on the spatial resolution of the geophysical parameters. The expectations will be met when parameters are available, except for the other parameters in version 1 of the MACC-RAD Service. These parameters will have the resolution of the re-analyses produced by ECMWF, i.e. a few tens of km. Smart spatial resampling procedures will be applied in version 2 to meet users' expectations.

Request	Irradiance, illuminance	Snow cover	Other parameters
Present services	Yes	-	-
Transition Service	Yes	Yes	-
MACC-RAD v1	Yes	Yes	No
MACC-RAD v2	Yes	Yes	Yes

Table 4.2. Compliance with the users' expectations regarding spatial resolution (5 to 10 km)

Table 4.3 shows the compliance of the services with respect to users' expectations on the temporal resolution. The expectations will be met for irradiance and illuminance. It is not expected to have hourly values of snow cover. As for other parameters, daily and monthly values will be available. Smart temporal resampling procedures will be applied in version 2 to meet users' expectations.

Request	Irradiance, illuminance	Snow cover	Other parameters
Present services	Yes – Yes - Yes	-	-
Transition Service	Yes – Yes - Yes	No – Yes - Yes	-
MACC-RAD v1	Yes – Yes - Yes	No – Yes - Yes	No – Yes - Yes
MACC-RAD v2	Yes – Yes - Yes	No – Yes - Yes	Yes – Yes - Yes

Table 4.3. Compliance with the users' expectations regarding temporal resolution: hour – day - month

Table 4.4 shows the compliance of the services with respect to users' expectations on the provision of time-series and maps. The present services deliver time-series as a standard product and maps on request. The situation will remain the same till the whole inclusion of the MACC-RAD Service version 2 of a mapping capability to provide maps as standard products.

Request	Time-series	Maps
Present services	Yes	On request
Transition Service	Yes	On request
MACC-RAD v1	Yes	On request
MACC-RAD v2	Yes	Yes

Table 4.4. Compliance with the users' expectations regarding provision of time-series and maps

4.2. Metadata and ancillary information

Table 4.5 shows the compliance of the services with respect to users' expectations on the metadata for discovery and exploitation. The present services use metadata for exploitation only. The transition service will be present in GEOSS catalogues due to the use of metadata for discovery. These metadata will be INSPIRE-compliant. Exploitation metadata in the MACC-RAD Service will be based on the on-going work of the GEOSS Architecture and Data Committee.

Request	Discovery	Exploitation
Present services	No	Yes
Transition Service	Yes (INSPIRE)	Yes
MACC-RAD v1	Yes (INSPIRE)	Yes (GEOSS)
MACC-RAD v2	Yes (INSPIRE)	Yes (GEOSS)

Table 4.5. Compliance with the users' expectations regarding metadata for discovery and exploitation

Table 4.6 shows the compliance of the services with respect to users' expectations on the ancillary information. The present services deliver flags and quantities relating to interpolation, reliability and uncertainty. This will remain in the forthcoming services with enhancements. In addition, data input to the method will be delivered by the MACC-RAD Service.

Request	Data input to method	Flag on interpolation	Reliability	Uncertainty
Present services	No	Yes	Yes	Yes
Transition Service	No	Yes	Yes	Yes
MACC-RAD v1	Yes	Yes	Yes	Yes
MACC-RAD v2	Yes	Yes	Yes	Yes

Table 4.6. Compliance with the users' expectations regarding ancillary information

4.3. Access to data

Table 4.7 shows the compliance of the services with respect to users' expectations on the depth of the archive (10 years at least) and the age of the data. The services meet the demand on this point.

Delivering real-time products, i.e. having less than a few hours, will be technically difficult and is not in the scope of the MACC-RAD Service. The method to be used in the transition service and MACC-RAD Service requests inputs that cannot be provided in real-time. The delay in obtaining these inputs leads to a delay in provision of SSI products.

In addition, data policy and downstream services should be taken into account. Disseminating very recent data is a sensitive topic subject to the data policy of the various providers and that could be harmful to markets generated by downstream services and further, to the companies behind.

Request	Archive (at least 10 years)	Archive (10 recent years)	Recent (last month)	Near-real time (last hours/days)
Present services	Yes	Yes	Yes	Yes
Transition Service	Yes	Yes	Yes	Yes
MACC-RAD v1	Yes	Yes	Yes	Yes
MACC-RAD v2	Yes	Yes	Yes	Yes

Table 4.7. Compliance with the users' expectations regarding the depth of the archive and the age of data

Table 4.8 shows the compliance of the services with respect to users' expectations on the use of the Web and format of data. The present services use the Web for ordering and delivering data. Data are supplied in the form of text files (CSV) or Excel-like spreadsheets. The forthcoming services will meet the expectations.

Request	Use the Web	CSV files or spreadsheets
Present services	Partly	Yes
Transition Service	Yes	Yes
MACC-RAD v1	Yes	Yes
MACC-RAD v2	Yes	Yes

Table 4.8. Compliance with the users' expectations regarding use of the Web and format of data

4.4. Documentation

Table 4.9 shows the compliance of the services with respect to users' expectations on documentation. The present services meet the demand for documentation. Many documents are on-line. The forthcoming services will enhance the documentation, which will be on-line.

Request	Scientific	Users guide	Workflow / procedures	Quality	List / catalogue	Data policy
Present services	Yes, on-line	Partly, on-line	Partly, on-line	Partly, on-line	Yes, on-line	Yes
Transition Service	Yes	Yes	Yes	Yes	Yes	Yes
MACC-RAD v1	Yes	Yes	Yes	Yes	Yes	Yes
MACC-RAD v2	Yes	Yes	Yes	Yes	Yes	Yes

Table 4.9. Compliance with the users' expectations regarding documentation

4.5. Quality of service

Table 4.10 shows the compliance of the services with respect to users' expectations on the quality of service as a whole. The present services have taken steps to meet these expectations. The forthcoming services will follow this policy with improvements.

Request	Delivery procedure	Customers desk	Helpdesk	Automated access
Present services	Yes	Partly	Partly	Partly
Transition Service	Yes	Yes	Yes	Yes
MACC-RAD v1	Yes	Yes	Yes	Yes
MACC-RAD v2	Yes	Yes	Yes	Yes

Table 4.10. Compliance with the users' expectations regarding the quality of service as a whole

4.6. Monitoring quality

Table 4.11 shows the compliance of the services with respect to users' expectations on the quality assurance and control.

The present services perform regularly validation of their products using ground measured data of opportunity. The validation procedure is now standardised thanks to the efforts made in the projects IEA SHC 36 and MESoR. Other manual procedures include a visual analysis of annual patterns for several years and a single geographical site, or visual inspection of images of SSI or other data in a movie.

In the future, it is foreseen to follow the same path for the transition service, and then, to exploit the re-analyses from ECMWF. It is foreseen to be able to report daily to customers. There will be two approaches in validation.

The first one consists in comparing reliable ground data with products. It will be performed as often as possible. It aims at assessing the uncertainty of the products. A model of uncertainty can be established or improved that provides for any instant the plausible uncertainty level of the SSI, given known explanatory variables such as the solar zenithal angle or the temporal variability of the SSI.

The second approach consists in comparing re-analyses with products. It will be performed once a day. Discrepancies are expected between both assessments. However, it is expected that a model can be found that explains these discrepancies as a function of known explanatory variables. Therefore, the distance between products and re-analyses can be predicted. It will be used to monitor the quality of products: large values should indicate suspect products. This approach is only sketched here. Its implementation will necessitate a great deal of effort and care.

The present services monitor the workflow at the following points:

- reception of the Meteosat images,
- missing lines in an image, position of extreme lines and columns in image,
- storage of images of radiance in the temporary archive,
- storage of clear-sky indices in the HelioClim databases,
- smooth running of each piece of software.

This will improve in the forthcoming services. More points will be controlled and reporting to management will improve. The future method Heliosat-4 to compute SSI is more sophisticated than the current method Heliosat-2. Monitoring its smooth running will require more control points.

The present services do not have automated procedure to monitor the quality of the service. Efforts are made on an opportunity basis to warn customers about planned shutdowns. Efforts are planned in the forthcoming services. It is expected to establish a few control points, such as monitoring the number of connected customers and the computers' capability, to report automatically to the management, and store reports in an archive. The MACC-RAD Service will comprise more control points and automated warning to customers. Enhanced reporting will be added in the future and daily controls of the interfaces to Web services (i.e. access to products) will be performed.

Request	Scientific validation	Monitoring workflow	Monitoring service
Present services	Using ground data of opportunity, standardised procedure	Two control points, warning	None
Transition Service	Using ground data of opportunity, standardised procedure	More control points	Reporting to management, archive of incidents, early warning to customers
MACC-RAD v1	Systematic control with re-analyses, warning, ground data of opportunity	Monitor each element, warning	Reporting to customers and management, archive, early warning
MACC-RAD v2	Daily control with re-analyses, ground data of opportunity, reporting to customers	Enhanced control	Enhanced reporting, archive, early warning, daily control of interfaces to Web services

Table 4.11. Compliance with the users' expectations regarding the quality assurance and control

PART B. CREATING DATABASES

5. The databases HelioClim and SOLEMI

The databases HelioClim and SOLEMI originate from a processing of Meteosat images provided by Eumetsat, a European agency located in Darmstadt, in Germany.. The Meteosat satellites are geostationary and located over the Gulf of Guinea, at longitude 0 approximately. The currently operational satellite is called Meteosat Prime. As it is aging, the Meteosat Prime is replaced regularly and since 1998, the "old" satellite is shifted eastwards over the Indian Ocean, at 63°E; it is then called Meteosat East. Figure 5.1 depicts the geographical areas covered by both satellites and by SOLEMI.

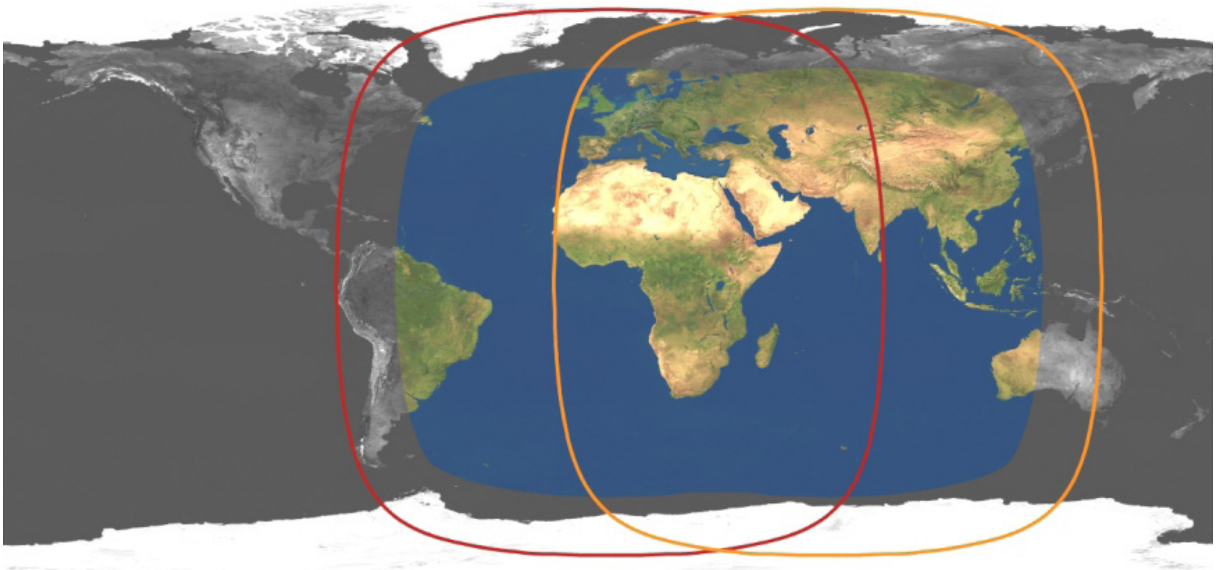


Figure 5.1: Field of view of the Meteosat Prime (in red) and Meteosat East (in orange). The blue area denotes the part of the area where irradiances can be computed; this is the coverage of the database SOLEMI.

Since 2004, a new series of Meteosat satellites is in operation: Meteosat Second Generation covers the same area than the prime satellites. The Meteosat First Generation satellites were operated concurrently till 2006.

DLR has a complete copy of the Eumetsat archives of images acquired by the satellites Meteosat First Generation back to 1984. Raw data from 1991 to June 2006 (Meteosat Prime) and October 1998 to December 2006 (Meteosat East) are easily and operationally accessible in the Data Information and Management System (DIMS) at DLR. These images are exploited to produce the database SOLEMI.

Since 2004, the images of the satellite Meteosat Prime (MSG) are routinely received at Armines and are processed in near-real-time, owing to a collaboration with Eumetsat and Meteo-France. These images cover Europe, Africa, the Atlantic Ocean and the Western part of the Indian Ocean (see left half of the blue area in Figure 5.1). These images are exploited to produce the database HelioClim-3.

The main properties of the databases HelioClim and SOLEMI are presented in Table 5.1.

	HelioClim-3	***SOLEMI***
Period	Since 2004	Since 1991
Temporal Resolution	15 min	1 hour
Geographical Coverage	Europe, Africa, Middle East	Europe, Africa, Middle East, Asia (except Eastern Asia)
Spatial Resolution	3 km at satellite nadir, approx. 5 km mid-latitude	3 km at satellite nadir, approx. 5 km mid-latitude
Parameters	Global total irradiance on horizontal plane	Global total irradiance on horizontal plane; direct normal irradiance
Processing	Near-real-time	On request
Update of the database	End of day	End of month
Version	V2	V14, build 98

Table 5.1. Main properties of the databases HelioClim-3 and SOLEMI

6. Brief description of the method converting satellite images into surface solar irradiance

6.1. History of the Heliosat methods

Several studies have demonstrated the feasibility of extracting the global solar surface irradiance (SSI) from geostationary satellites images like Meteosat (Tarpley, 1979; Möser, Raschke, 1984). Indeed, these satellites, which have passive sensors, observe the state of the atmosphere and the cloud cover above the target. These observations can be used to calculate the radiation reaching the ground.

Very early, the European Commission funded research to develop methods for retrieving the SSI from Meteosat images (Grüter et al., 1986). Among those, the Heliosat method was developed at MINES ParisTech (Cano et al., 1986). It became very popular and has been adopted by many researchers. Therefore, it underwent many changes aiming at improvements; the versions bearing major improvements were numbered (Heliosat-1, Heliosat-2, Heliosat-3).

The principles of Heliosat are illustrated in Figure 6.1. In most cases, a cloud exhibits a larger reflectance than the ground. Consequently, the appearance of a cloud in the field of view of the satellite sensor should result in an increase of the perceived signal: the cloud (target 2) appear brighter (whiter) than the ground (target 1). The magnitude of the difference between both targets is related to the depletion of the downwards radiation by the atmosphere. Of course, the situation where one can compares a cloudy pixel to a neighbour cloud-free pixel rarely happens. Therefore, Heliosat comprises a modelling of the SSI that should be observed by the sensor if the sky were clear for any pixel.

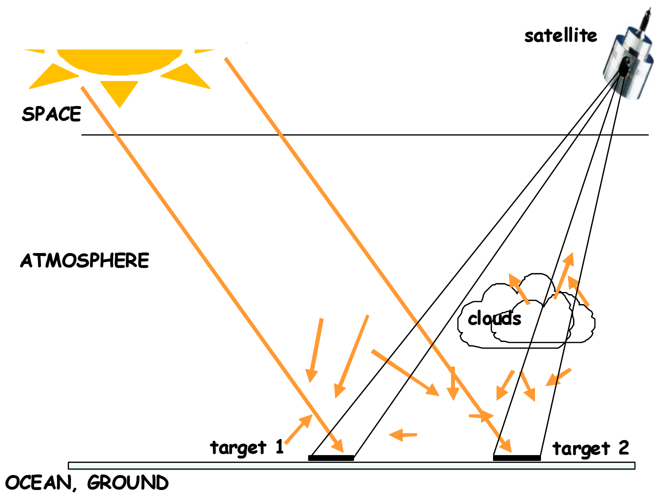


Fig.6.1: Measurement principle as used in cloud-index methods

The versions of Heliosat, which are inverse models, have in common to be divided into two parts regarding the physical modelling: converting the satellite image into a cloud index and converting the cloud index in irradiance. Therefore, they are called cloud index methods. Other methods with similar principles do not use cloud index. In the Tarpley's method (1979), the irradiance is estimated from the cloud fraction above the pixel.

The original Heliosat method makes use of the clearness index K_T. K_T is defined as the ratio of the SSI to the irradiance received at the top of the atmosphere. It characterizes the depletion of the solar radiation by the atmosphere. The cloud index n is converted into the clearness index by an empirical affine function $K_T = a\ n + b$, whose parameters a, and b, should be derived empirically by comparison with coincident ground measurements. These parameters can be computed for each location of ground station and then spatially interpolated to produce maps of parameters (Cano et al. 1986). They can also be averaged; the mean values are considered valid for a given region, e.g., Europe (Diabaté et al., 1988). Diabaté et al. (1989) observed that for Europe, three sets of parameters were needed: one for morning, one at noon, and one in the afternoon. A delicate part in the Heliosat method is the determination of the cloud-free instants. As Heliosat uses only one channel in visible range, the cloud-free instants should be detected by exploiting the time-series. A cloud-free instant should correspond to a minimum in the time-series, provided all other conditions are equivalent, which is not the case; for example, the sun position is changing within the day and also from day to day for the same hour. Espinar et al. (2009b) or Lefèvre et al. (2007) found that a relative error in the ground albedo leads to a relative error of the same magnitude in SSI under clear-sky, i.e., a relative error of order 10 % of the SSI in cloudy cases. Another delicate part in cloud-index based methods is the determination of the albedo of the brightest clouds. The error due to an error in this albedo increases as the sky is becoming cloudy; consequently, the relative error in the SSI can be very large, e.g., 60 % (Espinar et al., 2009b; Lefèvre et al., 2007).

Beyer et al. (1996) at the University of Oldenburg (Germany) produced a version called later Heliosat-1. It enhanced the original Heliosat method in several aspects. The major one is the adoption of the clear-sky index Kc instead of the clearness index K_T. The clear-sky index is defined as the ratio of the actual SSI to the SSI that would be received if the sky were clear. The great advantage of the substitution is that the relationship between Kc and n is universal and is now: $Kc = 1-n$. It has been found by these authors and confirmed by others that little was lost in quality by adopting this relationship for any part of the world and any time. Further work was done to remove partly the dependence of the received radiance with the viewing angle, thus leading to a more spatially-homogeneous cloud-index. In addition, work was performed on the determination of the ground and cloud albedoes. Several empirical parameters used in this determination, e.g., the allowed change in time of the ground albedo or the threshold to detect cloud-free instants were revisited and new values were proposed to better account for actual measurements of SSI made by European ground stations.

To improve the accuracy and the reliability of the estimation and to facilitate the implementation of the method, Rigollier et al. (2004) designed Heliosat-2 at MINES ParisTech. It exploits the advances proposed by Heliosat-1 and seeks at removing empirical parameters. This is done by adopting several models that have been published independently of Heliosat or Meteosat. This requests a calibration of the Meteosat images to convert gray values into radiances and then reflectances. The clear-sky model proposed in the European Solar Radiation Atlas (ESRA) was adopted (Rigollier et al., 2000). The albedo of the brightest clouds is given by the model of Taylor and Stowe (1984a, b). This version Heliosat-2 is presented hereafter.

Zarzalejo et al. (2009) combined the method Heliosat-2 and the statistical approach proposed in the original version to determine the relationship between the clear-sky index Kc and the cloud-index. Actually, they searched a relationship between ground measurements, the cloud index n and several statistical moments of n, e.g., median, first and third quartiles. It is a means to account for the local climate effects. They found unbiased results for 28 stations in Spain and the relative error decreases compared to the Heliosat-2 version.

The version Heliosat-3 has been designed in a collaborative EU-funded project led by University of Oldenburg, and comprising MINES ParisTech and DLR among others. It is characterized by a clear-sky model, called SolIS, which is an approximation of radiative transfer equations for fast implementation (Mueller et al. 2004).

6.2. Overview of the method Heliosat-2

Both HelioClim and SOLEMI are constructed by the same method, Heliosat-2. They differ in the implementation. The concept of Heliosat-2 is as follows. The irradiance I for an instant t and location (x, y) is equal to

$$I(t, x, y) = I_c\ (t, x, y)\ K_c(t, x, y) \tag{6.1}$$

where $I_c(t, x, y)$ is the irradiance for the clear-sky case; $K_c(t, x, y)$ is called the clear-sky index, is positive, and quantifies the depletion of I_c due to clouds. Thus, the method is based on *1)* a model of irradiance for clear-sky whose results are more or less depleted as a function of the cloud properties to yield actual irradiance. This concept is the basis of many published models outside Heliosat-2 (Rigollier et al., 2004).

The clear-sky index $K_c(t, x, y)$ is computed from the analysis of the Meteosat image at instant t and from the time-series of images prior to the current one. A cloud-index $n(t, x, y)$ is defined:

$$n(t, x, y) = [\rho_{cloud}(t, x, y) - \rho(t, x, y)] / [\rho_{cloud}(t, x, y) - \rho_g(t, x, y)] \tag{6.2}$$

where ρ, ρ_{cloud}, and ρ_g are the reflectances respectively observed by satellite for the pixel under concern, the brightest clouds, and the ground. The cloud index is close to 0 when the observed reflectance is close to the ground reflectance, i.e., when the sky is clear. It can be negative if the sky is very clean, in which case ρ is smaller than ρ_g. The cloud index increases as the clouds are appearing. It can be greater than 1 for clouds that are optically very thick.

An empirical relationship was derived from coincident ground measurements and Heliosat-2 results that links n to K_c (Figure 6.2):

$$\begin{array}{ll} n < -0.2 & K_c = 1.2 \\ -0.2 < n < 0.8 & K_c = 1 - n \\ 0.8 < n < 1.1 & K_c = 2.0667 - 3.6667\ n + 1.6667\ n^2 \\ n > 1.1 & K_c = 0.05 \end{array} \tag{6.3}$$

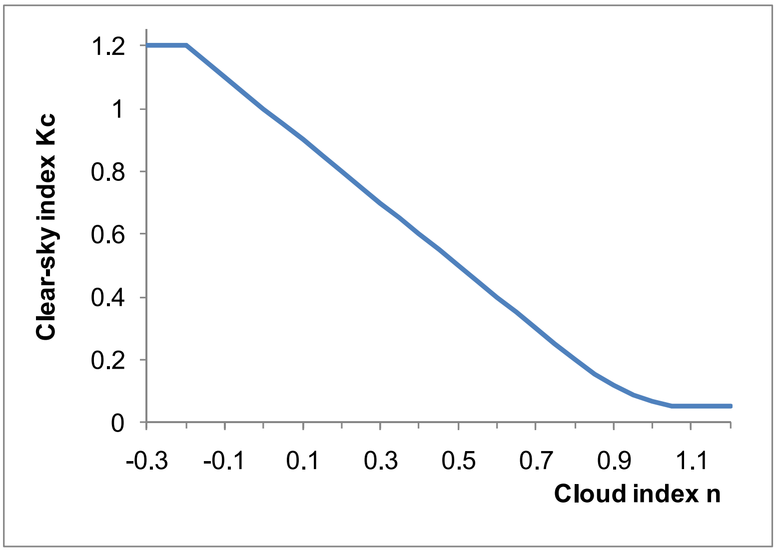


Figure 6.2: Relationship between the cloud index n and the clear-sky index Kc

For the computation of the DNI (direct normal irradiance) in the SOLEMI database, the following equation is used:

$$DNI = DNI_{clear} * \exp(a\, n) \qquad (6.4)$$

where *a* is a number which depends on the viewing geometry, the brightness temperatures in thermal infra-red of the pixel, and the spatial variability in the cloud index.

The model of irradiance for clear-sky used for HelioClim is that of the European Solar Radiation Atlas (ESRA); the clear-sky model for SOLEMI is the model of Bird. These models and their inputs are discussed in further sections.

There are limitations in the implementation of this concept. One major limitation is that $I_c(t, x, y)$ is unknown. Knowledge on aerosols and other influencing atmospheric parameters is too poor to permit to retrieve on an operational basis the irradiance $I_c(t, x, y)$ for any time and any location. Therefore, the best that can be provided is a typical value of $I_c(t, x, y)$ for this instant and location. In order to cope with that uncertainty, the clear-sky index $K_c(t, x, y)$ is allowed to be greater than 1 while it should not in principle.

6.3. Inputs to the clear-sky models

The clear-sky models require inputs that are now discussed.

6.3.1. Aerosols

Aerosols have the strongest influence on clear-sky irradiances through absorption and scattering processes. Since aerosol particles are much larger than the solar irradiance wavelength, the scattering processes follow the Mie scattering theory. Unfortunately scattering and absorption processes cannot be well discriminated from each other. Ångstrøm introduced a formula covering both processes that provides the optical thickness as a function of the wavelength λ:

$$k_\lambda = \beta\, \lambda^{-\alpha} \qquad (6.5)$$

β is the Ångstrøm turbidity coefficient indicating the aerosol content integrated in a vertical column of the atmosphere. The values are usually between 0 and 0.5. α is the wavelength exponent related to the size distribution of the aerosol particles. α usually is between 0.25 and 2.5 with an average of 1.3. Extreme values up to -0.5 or 3.0 are possible.

Modelling aerosols in the atmosphere is very difficult and is one of the major current tasks in atmospheric and climate research. Liu and Pinker (2005) give an overview of the current state of the art. The sources of aerosols are highly variable in space and in time. The interaction of the aerosol particles with the atmospheric trace gases and clouds is complex; the life time is approximatively one week and is rather short. Models are making good progress in capturing aerosol evolution, but the characterization of the sources is still difficult (Tanré et al., 2005). Current state-of-the-art data sets currently include satellite observations of aerosols, precursor trace gases, clouds and precipitation and networks of surface-based instruments assimilated into a chemical transport model.

Chemical transport models are off-line models driven by meteorological data or from global circulation models which take aerosol processes as an integral part within the simulation scheme. The available global data sets have made use of satellite data. Many of them have been developed for the use in climate models, which analyze direct and indirect effects of aerosols in global warming. Kinne et al. (2001, 2003) give a comparative overview to the different available aerosol data sets.

SOLEMI currently is an on request processing, so different aerosol data sets are selected based on comparisons with local ground data (if available) or on a regional basis (e.g. GACP and Aerocom tend to match better in European areas whereas NCAR-MATCH showed best results on the Arabian Peninsula).

GACP Data Set
The GACP (Global Aerosol Climatology Project) data set has been prepared by the NASA Goddard Institute for Space Studies (GISS, Tegen et al. (1997). They used a chemical transport model to calculate optical thickness for sea salt, soil dust, sulfate, carbonaceous aerosols and black carbon. It has a vertical resolution of 4° and a horizontal resolution of 5°. Figure 6.3 exhibits the annual average of the aerosol optical thickness in this data set.

Aerocom Data Set
The AeroCom project is an open initiative to compare different aerosol data sets and models (Kinne et al., 2005). Within this project aerosol fields of the model median were created: All AeroCom models were regridded to a 1° by 1° horizontal resolution data set and then the center value was picked at each model grid separately for each month. Outliers were eliminated, which otherwise would have affected the average. The data set covers aerosol optical thickness, single scattering albedo and the Angstrøm parameter. Figure 6.4 exhibits the annual average of the aerosol optical thickness in this data set.

MATCH Data Set
MATCH (Model of Atmospheric Transport and Chemistry) is a chemistry transport model with an irregular grid of about 1.9°x1.9°. Inputs to the model are surface properties, emission data bases and wind and rain fields from NCAR/NCEP reanalysis data. The model calculates aerosol uptake, transport, the chemistry and change with time and the deposition of aerosols. The direct output of the models is mass concentrations which can be converted into optical thicknesses. In general the model is capable of calculating aerosol data for actual days. A dataset covering the full Meteosat period back to 1984 is in preparation within MACC. Up to now, based on data from the years 2000 – 2005, a climatology of daily values has been created by averaging the respective day within each year. This gives 366 different values for each grid cell. Figure 6.5 exhibits the annual average of the aerosol optical thickness in this data set.

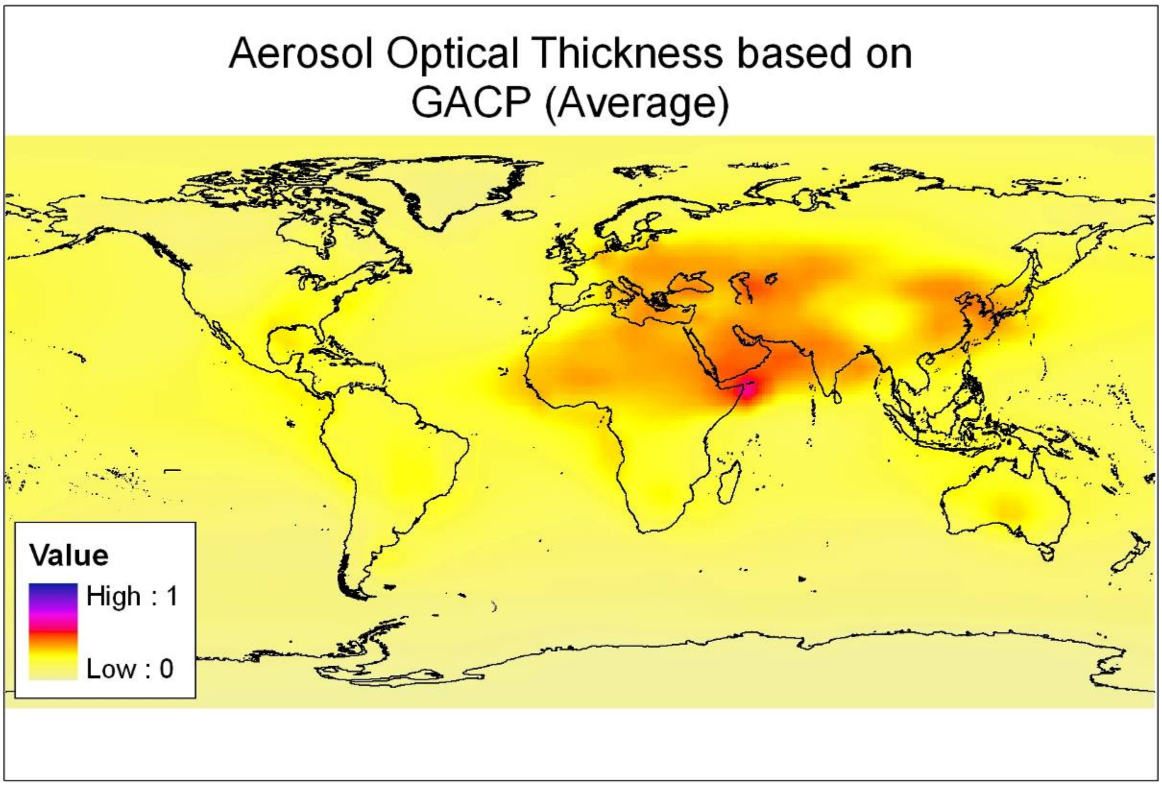


Figure 6.3: Annual average of the aerosol optical thickness in the GACP data set.

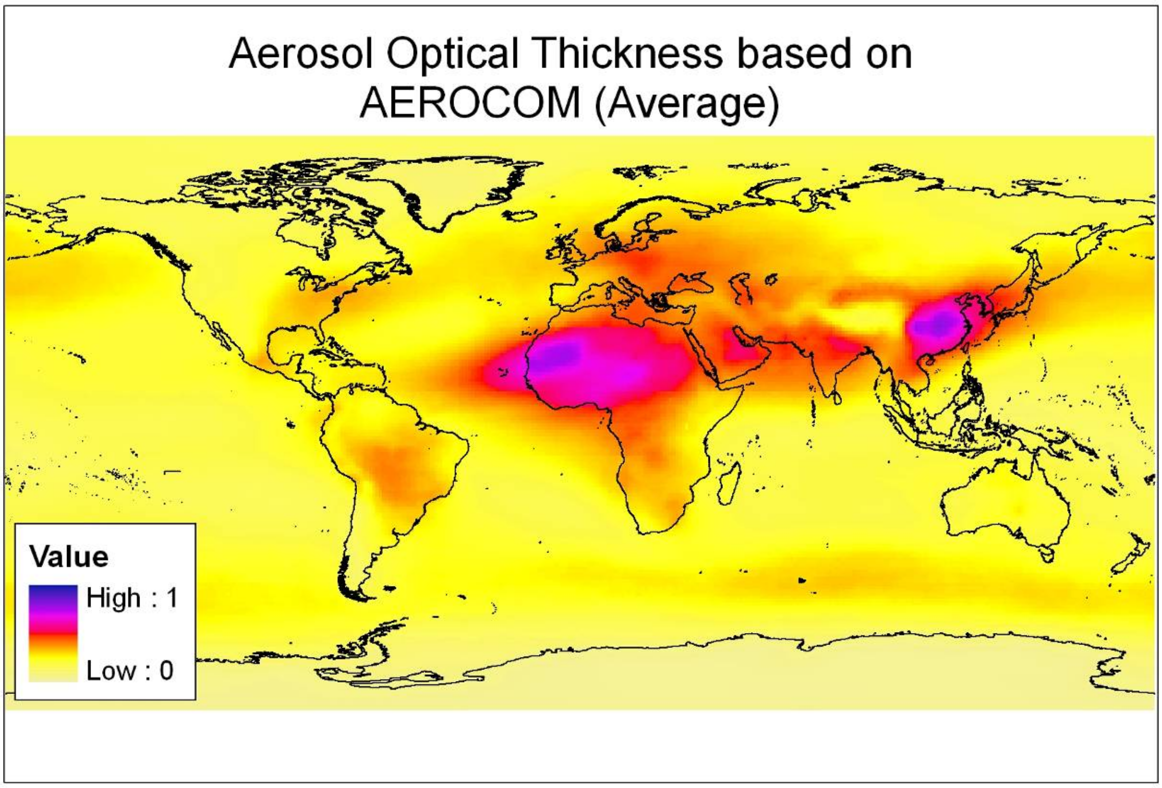


Figure 6.4: Annual average of the aerosol optical thickness for the Aerocom data set

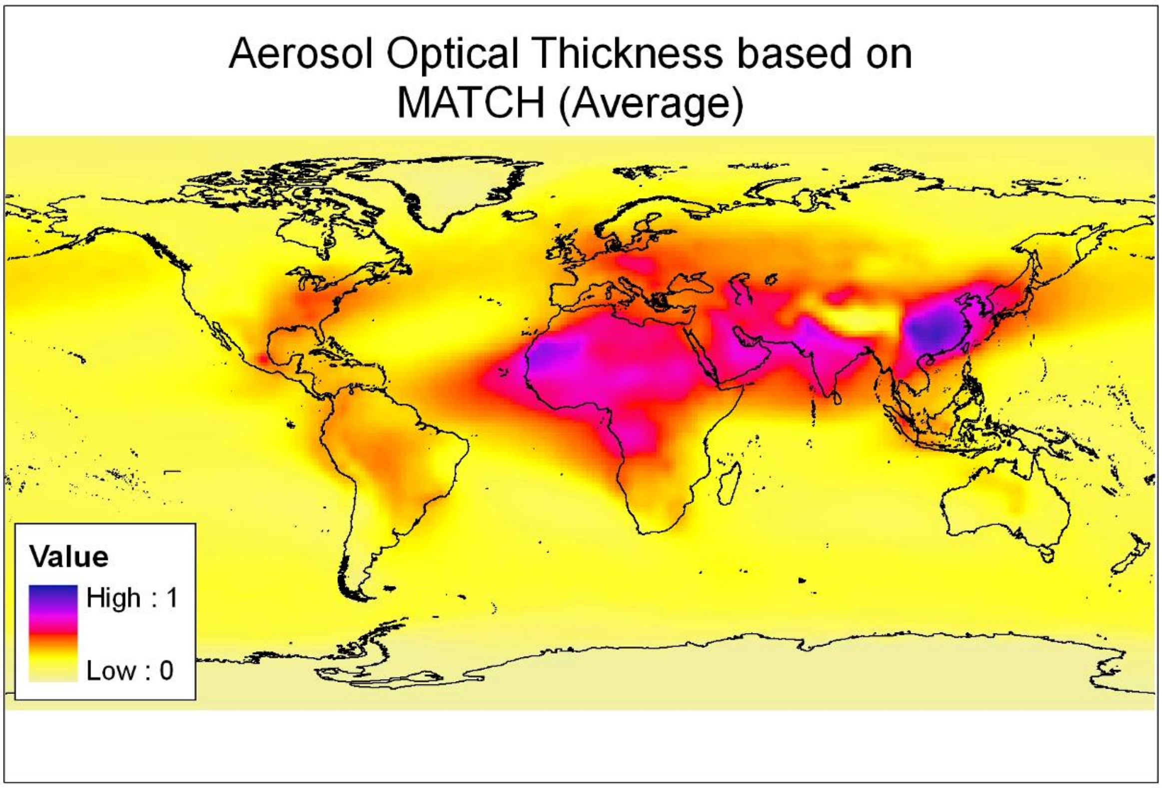


Figure 6.5: MATCH annual average (2000-2005) of the aerosol optical thickness.

6.3.2. Water vapour

Water vapour mainly absorbs the solar irradiance in the thermal spectrum and has a larger influence than ozone. Therefore a data set of the NCEP/NCAR-Reanalysis of the Climate Diagnostic Center (CDC-NOAA) with a spatial resolution of 2.5° x 2.5° is used. This data set is a joint effort of the National Centers for Environment Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) in the United States providing historic analysis from 1948 onwards. The reanalysis continues with the Climate Data Assimilation System (CDAS) so that the products are available to the present. A detailed description of the data set can be found in Kalnay et al. (1996); Kistler et al. (2001).

Trenberth and Guillemot (1998) evaluated the NCEP/NCAR data set and found a correlation of above 0.9 for most regions of the world for precipitable water from the NVAP (NASA Water Vapor Project) dataset (Randeletal, 1996).The comparison has been done for the period 1988 to 1992 when NVAP data exist. Large differences occurred in the tropics and the Sahara region.

6.3.3. Ozone

Ozone absorbs the irradiance predominantly at wavelength lower than 0.3 µm. Therefore the extinction of ozone is fairly low for the complete solar spectrum. The variability of ozone depends mainly on geographical latitude and time of the year. In the solar belt the ozone concentration is between 0.2 and 0.4 cm[NTP][1],. Since the effect of ozone is very small, a data set from the Total Ozone Mapping Spectrometer (TOMS) sensor is used (McPeters et al., 1998). The TOMS sensor uses a six-band sensor measuring backscattered earth radiances. It was originally flown in a 500 km high orbit starting in July 1996 but was raised to a 750 km orbit in December 1997 to increase coverage. In this orbit a 90 % daily coverage is

1 The unit cm[NTP] refers to the thickness under normal temperature and pressure.

achieved. The derived ozone columns from the level 2 product are gridded into a 1° latitude by 1.25° longitude level product. As the daily products only have a 90 % coverage and the influence of ozone is relatively small, a monthly data set is used. Compared to ground data, the derived ozone columns have a bias of about 1% (McPeters et al., 1998).

6.3.4. Linke Turbidity

The Linke turbidity factor (TL, for an air mass equal to 2) is a very convenient approximation to model the atmospheric absorption and scattering of the solar radiation under clear skies. It describes the optical thickness of the atmosphere due to both the absorption by the water vapour and the absorption and scattering by the aerosol particles relative to a dry and clean atmosphere. It summarizes the turbidity of the atmosphere, and hence the extinction of the direct solar radiation (WMO, 1981; Kasten, 1996). The larger TL, the larger the extinction of the radiation by the clear atmosphere.

The Linke turbidity factor denotes the transparency of the cloudless atmosphere. If the sky were dry and clean, TL would be equal to 1. When the sky is deep blue, TL is small. In summer, in Europe, the water vapour is often large and the blue sky is close to white. TL is larger than 3. In turbid atmosphere, e.g. in polluted cities, TL is close to 6 - 7.

A typical value of TL for Europe is 3. However, this value exhibits strong fluctuations in space and time as did the aerosols optical properties and the column-integrated amount of water.

A worldwide database for TL has been proposed by Remund et al. (2003). It has the form of gridded values, whose cells are squared and have a size of 5' of arc angle. There is one grid per month. For a given cell, the value of TL could be considered as representative of the monthly mean value averaged over several years. For a given day, one may interpolate the TL values for the month of this day and the closest month.

6.3.5. Conclusions

This section clearly demonstrates one of the current limitations of the methods for assessing the irradiance. The inputs used so far for the construction of the databases SOLEMI or HelioClim-3 are climatological values, whether they are aerosol properties and water contents or Linke turbidity factors. These climatologies cannot account for the intraday variability nor day-to-day of these parameters.

These inputs have a major influence on the value of the clear-sky SSI. The lack of variability impacts the quality of the retrieval of the SSI at daily and smaller time-scales. The impact is enhanced in the case of the DNI (direct irradiance at normal incidence).

The poor availability of accurate inputs is a recurrent problem, and not only in the retrieval of the SSI. The MACC Service will provide assessment of these inputs by the means of the re-analyses in the ECMWF model suite or the DLR/MATCH model version. In the transition step, we will incorporate more and more inputs from MACC. It is expected to have one value per day for each cell of say, 1° in size. The spatial description is coarse but a step forward in quality is expected by taking into account the day-to-day variability of the optical state of the atmosphere.

6.4. Brief description of the clear-sky models

6.4.1. The Bird model

The currently used Bird model has originally been proposed by Bird and Hulstrom (1981) and has later been modified by Iqbal (1983) as Model C. The broadband direct normal irradiance G_{dn} is calculated as:

$$G_{dn} = 0.9751\, G_{ext}\ \tau_r \tau_O \tau_g \tau_w \tau_a \qquad (6.6)$$

The factor 0.9751 is a conversion faction, since the model used for the development (SOLTRAN) considered the spectral interval of 0.3 µm - 3.0 µm. G_{ext} is the irradiance for a given instant on a plane normal to the sun rays at the top of atmosphere. The τ_x are the individual transmittances of the different atmospheric constituents. They are described below.

Air mass *m* – as used to describe water vapour and ozone transmission - is defined as:

$$m = \frac{1}{\cos\theta_z + 0.15(93.885 - \theta_z)^{-1.253}} \qquad (6.7)$$

For Rayleigh and aerosol transmission the SOLEMI model uses the air mass of Kasten and Young (1989) with a correction for the height *h* above sea level:

$$m_a = \frac{\frac{1-h}{10000}}{\cos\theta_z + 0.50572 * (96.07995 - \theta_z)^{-1.6364}} \qquad (6.8)$$

where θz is the solar zenith angle. The transmittance due to the molecular scattering τ_r is calculated by:

$$\tau_r = e^{-0.0903 m_a{}^{0.54}(1.0 + m_a - m_a{}^{1.01})} \qquad (6.9)$$

The transmittance τ_o due to ozone is:

$$\tau_c = 1 - 0.1611 U_3 (1.0 + 139.48 U_3)^{-0.3035} - \frac{0.002715 U_3}{(1.0 + 0.044 U_3 + 0.0003 U_3^2)} \qquad (6.10)$$

with

$$U_3 = l \cdot m \qquad (6.11)$$

where *l* is the vertical ozone layer thickness in cm and *m* is the uncorrected air mass. The transmittance τ_g due to uniformly mixed gases is given by:

$$\tau_g = e^{-0.0127 m_a^{0.26}} \qquad (6.12)$$

The transmittance τ_w due to water vapour is calculated from:

$$\tau_w = 1 - \frac{2.4959U_1}{(1.0 + 79.034U_1)^{0.6828} + 6.385U_1} \tag{6.13}$$

with

$$U_1 = w \cdot m \tag{6.14}$$

where *w* is the precipitable water in cm and *m* the uncorrected air mass. The aerosol transmittance τ_a at 550 nm is given by:

$$\tau_a = e^{-k_a^{0.873}(1.0 + k_a - k_a^{0.7088})m_a^{0.9108}} \tag{6.15}$$

where the aerosol optical thickness k_a at 550 nm is either calculated by

$$k_a = 0.2758k_{a,\lambda=0.38\mu m} + 0.35k_{a,\lambda=0.5\mu m} \tag{6.16}$$

or if α and β from the Angstrom law are known, the following equation from Mächler (1983) can be used:

$$\tau_a = (0.1245\,\alpha - 0.0162) + (1.003 - 0.125\,\alpha)\,e^{-\beta\, m_a (1.069\alpha + 0.5123)} \tag{6.17}$$

β can be calculated from the aerosol optical thickness k_a at 550 nm:

$$\beta = \frac{k_{550}}{0.55^{-\alpha}} \tag{6.18}$$

If unknown α is set to 1.3.

The clear-sky diffuse irradiance G_{diff} is calculated of three components, where $G_{diff,r}$ is the diffuse irradiance due to Rayleigh scattering, $G_{diff,a}$ due to aerosol scattering and $G_{diff,m}$ due to multiple reflections between surface and atmosphere. The diffuse irradiance due to Rayleigh scattering is:

$$G_{diff,a} = 0.79\, G_{ext} \cos\theta_z\ \tau_o \tau_g \tau_w \tau_{aa}\ F_c\, \frac{1 - \tau_{as}}{1 - m_a + m_a^{1.02}} \tag{6.19}$$

where τ_{aa} is the is the transmittance of direct irradiance due to aerosol absorption:

$$\tau_{aa} = 1 - (1 - \omega_0) \cdot (1 - m_a + m_1^{1.06}) \cdot (1 - \tau_a) \tag{6.20}$$

where ω_0 is the single scattering albedo of the aerosols. It is the relation of the radiation scattered by the aerosol to the total aerosol extinction. Bird and Hulstrom (1981) recommend to use 0.9 for ω_0 as long as no better value is available.

The aerosol-scattered diffuse irradiance after the first pass through the atmosphere is:

$$G_{diff,a} = 0.79 G_{ext} \cos\theta_z \tau_o \tau_g \tau_w \tau_{aa} F_c \frac{1 - \tau_{as}}{1 - m_a + m_a^{1.02}} \tag{6.21}$$

where τ_{as} is the transmittance of direct irradiance due to aerosol scattering:

$$\tau_{as} = \frac{\tau_a}{\tau_{aa}} \tag{6.22}$$

and *Fc* is the ratio of forward scattering to total scattering for which a value of 0.84 is recommended.

To calculate the irradiance by multiple reflections, the following expression for the atmospheric albedo ρ_a is suggested:

$$\rho_a = 0.0685 + (1 - F_C)(1 - \tau_{as}). \tag{6.23}$$

The irradiance due to multiple reflections is then given by

$$G_{diff,m} = \frac{(G_{dn}\cos\theta_z + G_{diff,r} + G_{diff,a})\rho_g \rho_a}{1 - \rho_g \rho_a} \tag{6.24}$$

where ρ_g is the ground albedo, which is set to 0.2. The diffuse irradiance is the sum of its components:

$$G_{diff} = G_{diff,r} + G_{diff,a} + G_{diff,m} \tag{6.25}$$

Finally the total clear sky irradiance G_{clear} on the horizontal surface is the sum of the direct and diffuse components:

$$G_{clear} = G_{dn} \cdot \cos\theta_z + G_{diff} \tag{6.26}$$

6.4.2. The ESRA model

The database HelioClim-3 is constructed by the means of the clear-sky model ESRA. This model was developed in the construction of the European Solar Radiation Atlas. It is based on Kasten's (1996) Rayleigh optical depth parameterization and the Linke turbidity factor at air mass 2. In this model, the global horizontal irradiance for clear sky, *G*, is split into two parts: the direct component, *B*, and the diffuse component, *D*. Each component is determined separately. This model is presented here very briefly. Details can be found in Rigollier et al. (2000) with revision proposed by Page and Remund and reported in Geiger et al. (2002).

The direct irradiance on a horizontal surface (or beam horizontal irradiance) for clear sky, *B*, is given by:

$$B = G_{ext} \cos\theta_z \exp(-0.8662\ TL(AM2)\ m\ \delta_R(m)) \tag{6.25}$$

where

- G_{ext} is the irradiance normal to the solar beam at the top of atmosphere,
- θ_z is the solar zenith angle. θ_z is 90° at sunrise and sunset,
- *TL(AM2)* is the Linke turbidity factor for an air mass equal to 2,
- *m* is the relative optical air mass (note that *m* is computed slightly differently from Eq. 6.7),

- $\delta_R(m)$ is the integral Rayleigh optical thickness.

The quantity $exp(0.8662\ T(AM2)\ m\ \delta_R(m))$ represents the beam transmittance of the beam radiation under cloudless skies. The relative optical air mass *m* expresses the ratio of the optical path length of the solar beam through the atmosphere to the optical path through a standard atmosphere at sea level with the sun at the zenith.

The diffuse irradiance falling on a horizontal surface for clear sky (or diffuse horizontal irradiance), *D*, also depends on *TL(AM2)* at any solar elevation. When the turbidity increases, the beam irradiance falls, the proportion of the scattered energy in the atmosphere increases and the diffuse irradiance normally rises. At very low solar altitudes and high turbidity, however, the diffuse irradiance may fall with turbidity increase due to large overall radiative energy loss in the atmosphere associated with long path length. Thus, the diffuse horizontal irradiance, *D*, is determined by:

$$D = G_{ext}\ Trd(TL(AM2))\ Fd(\theta_z, TL(AM2)) \qquad (6.26)$$

In this equation, the diffuse radiation is expressed as the product of the diffuse transmission function at zenith (i.e. sun zenith angle is 0°), *Trd*, and a diffuse angular function, *Fd*.

7. The quality of the retrieved irradiances

7.1. Principles. Comparisons. Limitations

The usual way of assessing the quality of retrievals of SSI derived from satellite images is to compare these SSI to coincident measurements performed at ground level. The typical accuracy of SSI measured in the global meteorological network is 3 to 5 % in terms of root mean square error. Therefore, the ground measurements can be seen as an accurate reference against which one may compare the SSI derived from satellite. The comparison is made by computing the difference between the two sets of measurements and analysing statistical quantities such as the bias or the root mean square error.

However, the actual situation is not that simple. Several limitations exist that make the assessment of the quality of retrieved irradiances a very difficult task.

The first limitation is the quality of the ground measurements. Well-maintained stations are rare. Data are often questionable. They should undergo extensive procedures for checking quality. Such procedures are often not enough and a final check must be performed by a trained meteorologist to discard suspicious data. For example, a series of ground-measured data sets was produced during the MESoR project[2], to serve as a reference for the benchmarking of any solar radiation product device from satellite data (Hoyer-Klick et al., 2008).

Even in case of accurate measurements, one often encounters a problem of time system. The time system for acquisition may be universal time, mean solar time, true solar time or local time. However, when stored in a database, there is a conversion in another time system, e.g., universal time. There is consequently a change of original values due to a resampling in time. This resampling can be done using various techniques, usually unspecified. In any case, it is not possible to return to the original values and there is a systematic shift of a fraction of an hour between the two sets of measurements. This leads to an additional difference.

Moreover, the networks do not always follow the existing standard for defining hourly data. This standard is defined by the WMO (WMO 1981): the time assigned to a data corresponds to the end of the measurement period. For example, a hourly data assigned to 11 am has been measured between 10 am and 11 am. In several cases, the time associated to a measurement represents the beginning of the period, or the middle of the period, or any instant within the period. Again, the comparison between the two sets requires the resampling of one of the sets at the expenses of decay in quality.

The limitations expressed above due to the time do not hold if one deals with daily, monthly or yearly averages or sums of SSI.

A severe limitation is due to the large differences in principles of measurements. Single point and temporally integrated data (ground measurements) are compared to spatially integrated and instantaneous data (satellite estimates). An assumption of ergodicity (e.g. here equivalence between the temporal and spatial averages) is usually made. This assumption is correct only if the field is spatially homogeneous over an area much larger than a pixel. This is generally false when a significant physiographic feature is present. Other local effects such as reflections on the surrounding slopes or the shadows of clouds may add to the difficulty in comparison.

2 Project MESoR (Management and Exploitation of Solar Resource Knowledge) funded by the European Commission, from 2007 to 2009 , http://www.mesor.org/

Perez et al. (1997), Zelenka et al. (1999) have observed the local variability of the SSI using measurements made by well-calibrated ground stations close to each other. They found that the variability itself is highly variable from one region to another. Nevertheless, they demonstrate that this variability cannot be ignored. Expressing this variability as the ratio of the variance relative to the mean value over the area, they found typical variability in hourly irradiances of 17 % for an area of 10 km in radius. This means that within a 10 x 10 km² area, irradiances measured by a series of similar inter-calibrated sensors would exhibit the same mean value but would differ from hour-to-hour, with a relative variance equal to 17 %. Therefore, observing a difference hour-to-hour of 17 % between a single pyranometer located in a pixel cannot mean that the satellite-derived irradiances are of bad quality.

The variability increases as the surface of the area increases. For example, it typically reaches 25 % for a radius of 30 km. It decreases as the time integration increases. For example, it is down to 10 % for daily values and a radius of 10 km.

Zelenka et al. (1999) analyzed the real accuracy of satellite estimations of hourly SSI. They suggest that for a relative deviation of 23 % (root mean square error) between ground measurements and satellite estimations, only half of it is due to the estimation method itself. The difference comes from:

- error on the measurements provided by the pyranometer (3 to 5 %);
- error due to the spatial variability of solar radiation within the pixel (5 to 8 %)
- error due to spatial and temporal heterogeneity of the compared data, e.g. assuming ergodicity (3 to 5 %) as discussed above.

7.2. Measures of performance

Guidelines of the benchmarking procedures of solar radiation products derived from satellite data, have been proposed by the MESoR project, in order to measure the quality of these products with a common scheme (Beyer et al., 2008). The quality of a product is defined by various statistical quantities that measure the discrepancies between products and ground data considered as a reference.

These different measures are described below. They are sensitive to different properties in the products and by this, allow for an assessment of the uncertainty specific to a given application, and a ranking of the quality of different products. We present here the benchmarking procedure for SSI data.

7.2.1. Measures for the quality of modelled irradiance data

Usual measures

Following the ISO standard (1995), the MESoR project recommends to compute the difference: modelled – measured, for each pair of values, and summarize these differences by the bias (alos, called mean bias, MB), the root mean squared difference (RMSD) and the correlation coefficient. The mean bias difference (MB) is defined by:

$$MB = \frac{1}{n}\sum_{i=1}^{n}\left(x_e(i) - x_m(i)\right) = \overline{x_e(i)} - \overline{x_m(i)}$$

$$\begin{aligned} &n : \text{number of data pairs} \\ &x_e(i) = \text{modeled data} \\ &x_m(i) = \text{measured data} \end{aligned} \qquad (7.1)$$

and the RMSD by:

$$RMSD = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\,x_e(i) - x_m(i)\,)^2} \quad . \tag{7.2}$$

The corresponding relative differences are rMB and rRMS:

$$rMB = \frac{MB}{\overline{x_m}} \tag{7.3}$$

$$rRMS = \frac{RMS}{\overline{x_m}} . \tag{7.4}$$

The standard deviation *σ* can be calculated from the MB and RMSD:

$$\sigma = \sqrt{RMSD^2 - MB^2} \; . \tag{7.5}$$

The correlation coefficient *CC* is computed as follows:

$$CC = \frac{\sum_{i=1}^{n}\left(x_e(i) - \overline{x_e}\right)\cdot\left(x_m(i) - \overline{x_m}\right)}{\sqrt{\sum_{i=1}^{n}\left(x_e(i) - \overline{x_e}\right)^2 \cdot \sum_{i=1}^{n}\left(x_m(i) - \overline{x_m}\right)^2}} . \tag{7.6}$$

Quality measures based on the Kolmogrov-Smirnov Test

However, these parameters are often insufficient to establish a complete, coherent comparison for benchmarking. Additional measures can be introduced that quantify the discrepancies between the cumulative distribution functions (CDFs). A comprehensive approach to an analysis of the deviations of measured and modelled CDFs is described by Espinar et al. (2008). It is based on the Kolmogorov-Smirnov (KS) test and defines new parameters to quantify the similarity of the two CDFs. Although there are several statistical tests and ways of evaluating the goodness of a model, the KS test has the advantage of making no assumption about the data distribution, and is thus a non-parametric, distribution-free test.

The KS test tries to determine if two data sets differ significantly. The test consists of comparing the distribution of a dataset to a reference distribution. This can be done by converting the list of the *N* data points to an unbiased estimator $S(x_i)$ of the CDF. The KS statistic *D* is defined as the maximum value of the absolute difference between the two CDFs:

$$D = \max|S(x_i) - R(x_i)| \tag{7.7}$$

where $R(x_i)$ is the CDF of the reference data set. If the *D* statistic is lower than the threshold value V_C, the null hypothesis that the two data sets come from the same distribution cannot be rejected. The critical value depends on *N* and is calculated for a 99% level of confidence as:

$$V_c = \frac{1.63}{\sqrt{N}}, \quad N \geq 35 \tag{7.8}$$

This test detects smaller deviations in cumulative distributions than the χ^2 test does. However, instead of using the original one, an extended KS test is used, in which the distances between the CDFs are calculated over the whole range of the variable *x*, i.e. the solar radiation. A discretisation in *m* levels is applied here. In the project MESoR, setting *m* to 100 was found a reasonable choice. Greater orders of magnitude for *m* are not recommended since it implies more computational cost for no improvement in the accuracy of the result. The interval distance *p* is defined as:

$$p = \frac{x_{\max} - x_{\min}}{m} \quad , \; m=100 \tag{7.9}$$

where x_{max} and x_{min} are the extreme values of the independent variable. Then, the distances between the CDFs are defined, for each interval, as:

$$D_n = | S(x_j) - R(x_j) | \; , \quad x_j \in \left[x_{\min} + (n-1)p, x_{\min} + np \right] \tag{7.10}$$

The representation of the values D_n, along with the critical value, gives the complete testing behaviour of the CDF with respect to the reference over the whole range. Thus, the extended KS test is very useful for model response assessments. However, although application of the KS test contributes valuable information, it only materializes in the acceptance or rejection of the null hypothesis. In the next sections new parameters are proposed, which, based on the estimation of the distance between the two CDFs for the sets compared, define quantitative measures that can be used to rank models.

Kolmogorov – Smirnov test Integral, parameter KSI

The KSI parameter (Kolmogorov-Smirnov test Integral) is defined as the integral of the area between the CDFs for the two sets. The unit of this index is the same for the corresponding magnitude, the value of which depends on it. As an example, the leftmost graph in Figure 7.1 shows the CDF (measured) for the data set of daily irradiation measured at the station in Arkona (Germany) over a period of 9 years (1995-2003) and the CDF of a corresponding satellite-derived data. In the rightmost plot the distances D_n between the two CDFs are displayed. The black dotted line represents the critical limit, V_c, calculated for the number of available data.

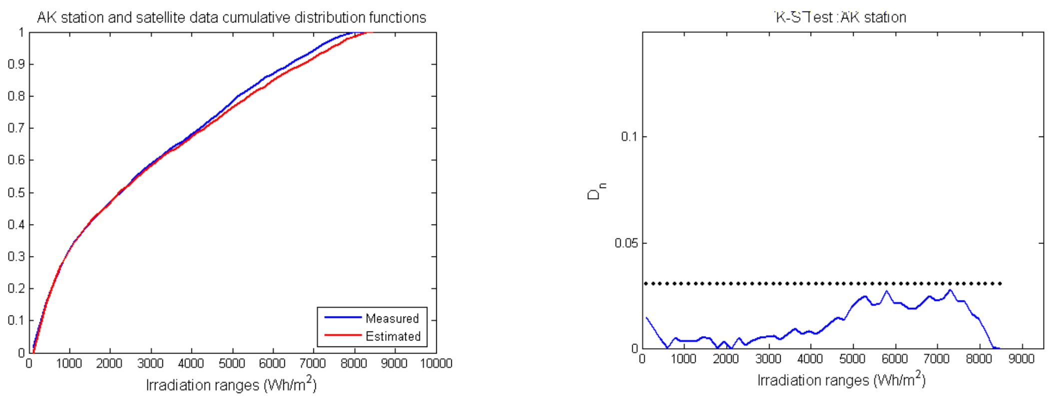


Figure 7.1: Plot of cumulative distribution functions for measured and modelled sets of daily irradiation and the distances between them, for the Arkona station (Germany). Courtesy of Annette Hammer, University of Oldenburg

The KSI is defined as the integral:

$$KSI = \int_{x\min}^{x\max} D_n d(x) \qquad (7.11)$$

As D_n is a discrete variable and the number of integration intervals is identical in all cases, trapezoidal integration is possible over the whole range of the independent variable *x.* A percentage of KSI is obtained by normalizing the critical area, $a_{critical}$:

$$KSI\% = \frac{\int_{x\min}^{x\max} D_n dx}{a_{critical}} * 100 \qquad (7.12)$$

where $a_{critical}$ is calculated as:

$$a_{critical} = V_c * (x_{\max} - x_{\min}) \qquad (7.13)$$

where V_c is the critical value for the level of confidence selected and (x_{max}, x_{min}) are the extreme values of the independent variable. Normalization to the critical area enables the comparison of different KSI values from different tests. The minimum value of the KSI index is zero, in which case, it can be said that the CDFs of the two sets are the same.

Parameter OVER_99

In the definition of this new parameter, the critical limit V_c is applied from the original KS test, calculated according to the number of data *N* in the set. For its estimation, only the areas of those distances between the CDF that exceed the critical limit are calculated.

OVER_99 refers to the fact that V_c is based on a 99% confidence level. Basically, other confidence levels can be chosen. To calculate the OVER_99, the auxiliary vector for the values that exceed the critical value *aux* is generated. If any of the components does not exceed the critical value, its corresponding component in the auxiliary vector is zero.

$$aux = \begin{cases} D_n - V_c & if\ D_n > V_c \\ 0 & if\ D_n \leq V_c \end{cases} \qquad (7.14)$$

The OVER_99 and OVER%_99 parameters are then calculated as the trapezoidal integral of that auxiliary vector and its corresponding normalization to the critical area:

$$Over\_99 = \int_{x\min}^{x\max} aux\ dx \qquad (7.15)$$

$$Over\%\_99 = \frac{\int_{x\min}^{x\max} aux\ dx}{a_{critical}} * 100 \qquad (7.16)$$

where $a_{critical}$ is the same as the one calculated in the *KSI* and *KSI%* parameters.

Like the KSI index, the OVER_99 has the same unit as the variable that is evaluated. This parameter enables a value to be marked that generates two types of results: the sets that behave statistically the same and those that do not. This is an advantage compared to the results supplied by the classical parameters RMSD and MB, which do not provide the possibility of making this differentiation.

Comparability of results
A yet problematic feature of the proposed tests is the dependency of the critical value on the number of samples. The more the samples used in the analysis, the lower the critical value. It can be explained by an example. Assume that the CDFs of two hourly data sets are compared for one year (about 4500 values with the sun above the horizon) and that they are judged similar. If two years are taken, the critical value is *1/sqrt(2)* times smaller than before. If the difference between the CDFs is still the same, they might now be judged as different because of this change in critical value. It has to be evaluated if constant values of the critical value should be used for certain time steps (e.g. hourly, daily, monthly data).

7.2.2. Selection of valid data pairs for benchmarking

An important factor to achieve comparable benchmarking results is the selection of valid data pairs (modelled and measured) which are taken into account. The project MESoR recommends the use of data pairs only for which:

- the ground data has passed a QC procedure (e.g. Hoyer-Klick et al. 2008);
- measured global irradiance is greater than zero (this excludes night values and missing measurements);
- the modelled value is available.

Averages are calculated from all valid data pairs. If a subset is selected (e.g. a sun zenith angle interval) averages are calculated from all valid data pairs within this subset.

There are two extreme ways to measure the quality when data from multiple stations are available. One of these ways is to concatenate all data pairs into a single series to analyse. In this way, each data pair has the same weight in the analysis. The other way is to perform the analysis for each station independently and then to compute the mean values of the different measures. In this way, each station has the same weight irrespective of its number of samples in the analysis. Both ways have their merits and drawbacks. If all stations belong to the same "radiation climate", then, it would be justified to adopt the first way. On the contrary, if the stations belong to different climates, e.g., one station in Sahel, and three stations in Germany, then, concatenating all data will give more weight on the German stations, with the risk that discrepancies specific to the Sahel station may disappear in the analysis; in this case, the second approach should be preferred. Actually, it is highly preferable to perform the analysis for each station individually and to discuss the possible discrepancies in quality measures with respect to the properties of these stations.

The same discussion may apply to time aggregation. For example, assume that daily values are available for a year but with gaps, e.g., 15 days available per month in January, February and March, all days available for the other months. Obviously, if one performs an average of all days for assessing the performance over a year, this assessment will be biased by the low number of days in winter. There are several possible solutions. It is recommended to analyse the influence of the choice of a solution.

7.2.3. Summary on the measures proposed

The basis for the proposal of the new parameters is the KS test, but the aim is its quantification to gain numerically comparable results from the different sets. Therefore, the parameters KSI and OVER are introduced. The KSI estimates the area between the two CDFs. The OVER is also an estimate of the area between the CDFs, but only for the parts where the critical value distance V_c is exceeded. In addition, it provides a value comparable between different data sets.

The OVER% is the only one that enables to observe a significant difference in the behaviour of the comparison. It shows whether the critical value is passed or not, so the classification has to account for this value first, classifying those stations as best that have an OVER equal to zero. That means the sets compared are statistically so similar that they could be the same one.

The differences found in the comparison of the data may in turn have different explanations. Thus, they may originate both in the behaviour of the measured data at a specific station, such as recording errors, and in the behaviour of the estimates made from the satellite images in the pixels for complex topographies.

7.3. Typical performances of existing services SoDa and SOLEMI

The quality of the products provided by the existing services SoDa and SOLEMI has been assessed at several occasions using the MESoR – IEA procedure described previously. The results are published in articles, communications and on the Web site of the SoDa Service.

We present here a sample of the many comparisons made for the products supplied by SoDa and SOLEMI. The example is drawn from the work made by Pierre Ineichen, University of Geneva, who made several comparisons between ground measurements and the products from SoDa (HelioClim-3) and SOLEMI. This work was presented at the meeting of the MESoR project in Geneva in December 2008.

Table 7.1 presents the results for the products HelioClim-3 and Table 7.2 those for the products SOLEMI. These tables deal with hourly means of global irradiance, expressed in W/m². The period is the full year 2005.

HelioClim-3		Mean value	N	R²	rMB%	rRMS%	KSI%	Over%_99
Toravere	Estonia	256	3789	0.937	3	32	89	14
Nantes	France	294	4113	0.933	2	30	40	1
Vaulx-en-Velin	France	310	4066	0.966	5	22	65	1
Thessaloniki	Greece	376	3820	0.976	-4	17	54	4
Geneva	Switzerland	292	4283	0.969	2	23	39	0
Payerne	Switzerland	294	4268	0.955	-5	26	67	8
Cabauw	UK	261	3803	0.962	-1	23	70	17
Camborne	UK	249	4235	0.953	5	29	72	12
Lerwick	UK	199	3624	0.906	10	43	105	40

Table 7.1. Benchmarking of SoDa (HelioClim-3) products: hourly averaged global irradiance. "Mean value" is the average of the ground measurements; "N" is the number of data pairs; "R²" is the squared correlation coefficient; other quantities are defined in the text.

SOLEMI		Mean value	N	R²	rMB%	rRMS%	KSI%	Over%_99
Toravere	Estonia	256	3789	0.948	-3	27	38	0
Nantes	France	294	4113	0.937	2	29	27	3
Vaulx-en-Velin	France	310	4066	0.950	5	26	60	17
Thessaloniki	Greece	376	3820	0.971	3	18	43	1
Geneva	Switzerland	292	4283	0.954	4	27	77	12
Payerne	Switzerland	294	4268	0.957	1	25	33	5
Cabauw	UK	261	3803	0.950	0	26	40	5
Camborne	UK	249	4235	0.950	2	28	32	8
Lerwick	UK	199	3624	0.935	3	33	70	20

Table 7.2. Benchmarking of SOLEMI products: hourly averaged global irradiance. "Mean value" is the average of the ground measurements; "N" is the number of data pairs; "R²" is the squared correlation coefficient; other quantities are defined in the text.

It is not the scope of this document to discuss specifically these tables and to compare the results. Nevertheless, the reader may note that the performances are very good in view of what is available currently. These performances are typical of those observed for the SoDa and SOLEMI products in other occasions.

The performances increase as the aggregation period increases, except for the bias of course.

The reader may take note of the variability of the quality parameters for the same product for sites belonging to the same geographical area. For example, in Table 7.1, one finds a relative bias (rMB%) of 2 for Nantes and 5 for Vaulx-en-Velin. On the contrary, the rRMS is larger for Nantes than for Vaulx-en-Velin: 30 versus 22. This can also be observed in UK stations. Even in geographical areas a priori fairly similar with respect to radiation climate, one cannot transpose accurately the performances observed at one site to another one. The same observation can be made when comparing benchmarks for the same site but different years. This does not help customers unfortunately but it is better to be aware of it.

There are several reasons to this variability. Several of them have been discussed already. Others are presented below.

7.4. Known problems

Radiative transfer in the atmosphere is a complex phenomenon. In an operational method for the assessment of the SSI, methods should run fast at the expenses of the complexity of the models and therefore of the accuracy of the retrieved SSI. For example, several interactions between radiation and ground (e.g., reflections on the surrounding slopes) or clouds (reflections on the sides of clouds, multi-layered cloud ...) are currently not taken into account. Another problem is the low level of availability of data characterising the optical state of the atmosphere under clear skies. Climatological data are used by default at the expenses of a misrepresentation of the temporal variability of the SSI.

7.4.1. Sub-pixel phenomena

There will be an error when the condition differs from the average state. The frequency (15 min) of observation by satellite is very satisfactory to describe the transitional phenomena such as convection. But the size of the pixel is not adapted to the micro-meteorology. There is a spatial integration which smoothes the phenomena. Meteosat pixels have actually an elliptic shape and their average diameter ranges from 1 km to 8 km depending on the viewing geometry of the satellite. Fig. 7.2 shows a typical Meteosat First Generation pixel in Central Europe with N-S extent of about 4 km and E-W extent of about 3 km. The resolution of this satellite at sub satellite point is 2.5 km at ground.

Figure 7.2. Typical Meteosat pixel in Europe with sizes of about 3x4 km².

In this example, one can note the presence of clouds in the ellipse, whose size is much lower than the pixel size.

7.4.2. Empirical parameters in method

Another limitation of the current methods is that are still included parameters determined empirically that significantly influence the quality of the results. Lefèvre et al. (2007) has shown that an error of 0.05 on the estimated ground albedo causes an error of 9 % on the estimated SSI. Similarly, an estimation error of 25 % on cloud albedo can cause up to 60 % error on SSI.

7.4.3. Change in terrain elevation within a grid cell in databases

The computation of the SSI from satellite images calls upon a digital terrain model (DTM) whose cell size fits that of the pixel. For example, the ESRA atlas (ESRA 2000) or the HelioClim-1 database (Lefèvre et al. 2007) exploits the DTM TerrainBase (TerrainBase 1995) whose cell size is 5' of arc angle, i.e. approximately 10 km at mid-latitude. The size of the cell is even larger for the NASA-SSE database: 1° of arc angle (Chandler et al. 2004) or for the ISIS database: 280 km (Lohmann 2006).

These sizes are too large to describe changes in altitude with a sufficient accuracy in areas of steep relief; large discrepancies can be found between the mean altitude of a cell and the altitude of a particular site within this cell (Figure 7.3). For example, in Switzerland, the altitude of the measuring station at Saentis Mountain is 2490 m while that provided by the DTM TerrainBase is 1126 m, i.e. an underestimation of 1364 m. Wahab et al. (2009) report that a difference in altitude of 300 m may induce a relative difference greater than 1 % on the monthly mean value of the SSI. This means that change in elevation must be accounted for.

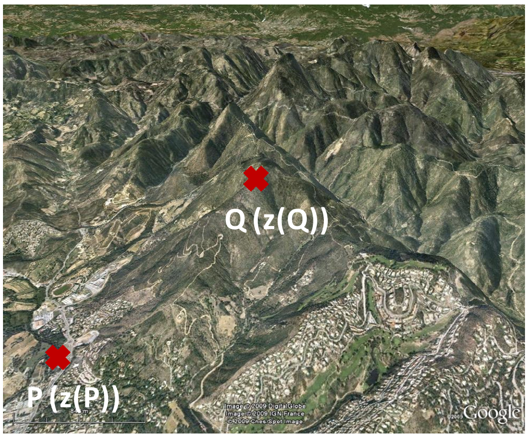


Figure 7.3.. Sample of cell in a SSI database. Change in altitude is very large between site P and site Q

In very steep relief, irradiance depends upon shadows cast on the sites by surrounding obstacles (Fig. 7.4) and not only on change in altitude.

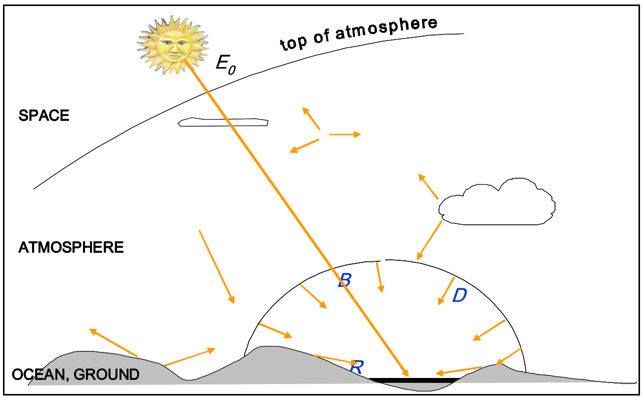


Figure 7.4. Incident irradiance in a complex terrain. B: direct irradiance; D: diffuse irradiance; R: irradiance reflected by nearby terrain

Figure 7.4 shows that the SSI on a horizontal surface is composed of the direct irradiance, diffuse irradiance partly masked by the surrounding mountains, and a reflected part R due to the reflexion on the surrounding slopes. Most often, if not always in operational methods, R is not accounted for; the irradiance calculations are done under the assumption of a flat terrain within the pixel. In that case, the tilt angle α and azimuth angle β of the element receiving the radiation are set to 0 and the cosine of the local incident angle θ is:

$$\cos\theta(0,0) = \cos\omega \cos\delta \cos\phi + \sin\delta \sin\phi \qquad (7.17)$$

where ω is the hour angle, δ is the solar declination, and ϕ is the latitude of the site.

In case of non-flat pixel, for each element (*dx, dy*) within a pixel, the cosine of the local incident angle θ is:

$$\cos\theta(\alpha, \beta) = (\cos\omega \cos\delta \cos\phi + \sin\delta \sin\phi) \cos\beta + \cos\omega \cos\delta \sin\phi \cos\alpha \sin\beta + \sin\omega \cos\delta \sin\alpha \sin\beta - \sin\delta \cos\phi \cos\alpha \sin\beta \qquad (7.18)$$

where α and β correspond to the direction of the local slope, respectively in azimuth and tilt. Thus, the SSI of the pixel should be modified by the ratio *R'*:

$$R' = \iint_{pixel} \cos\theta(\alpha(x, y)), \beta(x, y))\, dx\, dy / \cos\theta(0,0) \qquad (7.19)$$

7.4.4. Bidirectional reflectance and albedo

Reflexion properties of the ground are a function of the incident and viewing angles. Up to now, these parameters are not operational available. Figure 7.5 shows the angular variation of the reflectance of a coniferous forest in the near infrared (Oumbe 2009).

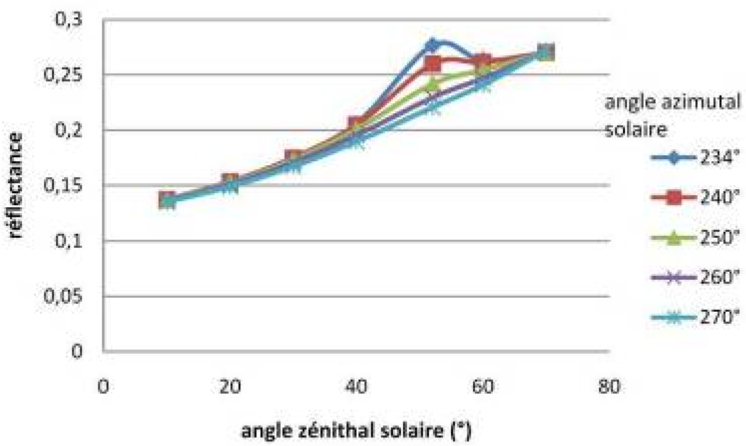


Figure 7.5. Example of variation in ground reflectance (vertical axis) with the solar zenithal angle (horizontal axis). Viewing zenithal and azimuthal angles are respectively 52° and 234°.

The change in reflectance with the angles can be large; it is greater than 0.1 in Fig. 7.5. It can be much larger in the specific case of oceans, where the reflectance depends also on wind speed and varies from values close to zero to values greater than cloud reflectance (Lefèvre et al. 2007). By considering the hemispherical albedo instead of the bidirectional reflectance, one commits a significant error on the part of irradiance reflected by the ground then backscattered by the atmosphere, thus contributing to the diffuse fraction of the SSI. This omission is very often made for operational reasons because of the lack of data describing the ground.

A similar effect can be found in case of clouds because cloud reflectance changes with illuminating and viewing angles. The method Heliosat-2 accounts for such changes by adopting the models of Taylor and Stowe (1984a, b).

7.4.5. Cloud vertical position – Snow cover

Contrary to objects at ground, clouds are located at different altitudes in the atmosphere. If the viewing angle is large, i.e. far from the satellite nadir, the parallax effect becomes noticeable for clouds at high altitude and not too thick. This results in an erroneous assessment of the geographical position of the cloud. The cloud will be assigned to a pixel farther from the nadir of the sensor than the actual one. The pixel over which the cloud is actually located will be seen as a cloud-free pixel and the SSI assessment will be inaccurate.

The current method Heliosat-2 does not account for the sudden appearance of snow; large errors may appear in the presence of snow cover in cloud-free atmosphere. The satellite derived irradiance values indicate a cloudy sky, since the snow covered pixels appear bright as clouds in the visible channels of the satellite images, as illustrated in Fig. 7.6.

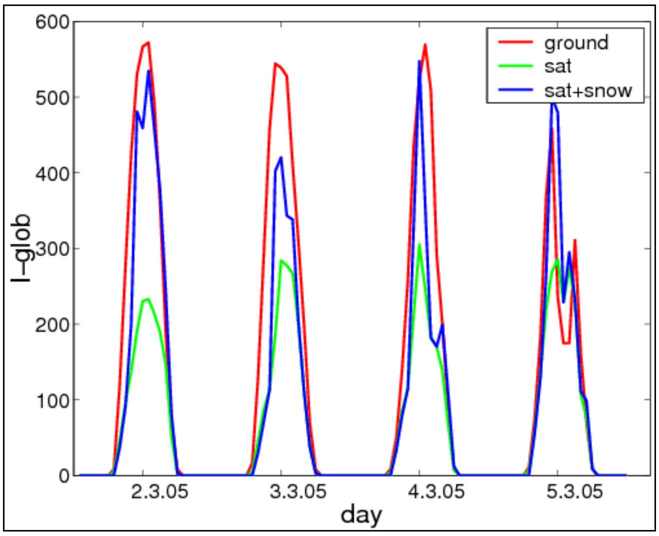


Figure 7.6. Example for satellite derived global irradiance with (blue) and without (green) snow detection in comparison versus ground measured values for a German station in March 2005 (source Univ. Oldenburg).

This figure stands for a German measuring station in March 2005. During this month, the sky was clear for many days and the snow was covering the ground. The ground measurements in red show large values in irradiance, while SSI retrieved by the Oldenburg method (similar to Heliosat-2) are much too low (in green). An attempt to correct this drawback was successful in this case (blue line).

7.4.6. Input data

Aerosol loading and water vapour amount are difficult to measure with remote sensing methods over land. The retrieval of aerosols is handicapped by the small aerosol reflectance and the perturbation of the weak signal by clouds and surface reflection. It can also be difficult to distinguish between water vapour and clouds. Thus, aerosols and water vapour data are usually taken from numerical model reanalyses and the accuracy and resolution are limited. These data are often available on a daily or monthly basis and with a resolution close to 1° or coarser. Furthermore, there are many different data sets available. It may be difficult to select a specific one. It may happen that the data set matching most of the validation sites may not be the best for a specific site. Figure 7.7 shows three different aerosol data sets. It can be seen that the absolute values and distributions are very different even if only the annual average is compared.

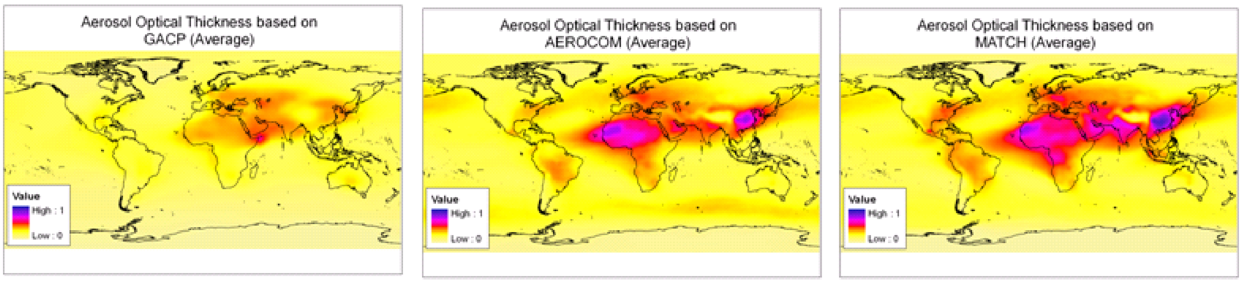


Figure 7.7. Different global annual average aerosol data sets. The colour scaling is the same on all three images.

Nonetheless, aerosol loading and water vapour amount are very variable in time and space and have a great influence on SSI, particularly in clear skies. Wald and Baleynaud (1999) demonstrate noticeable variation in atmospheric transmittance due to local pollution in cities at scale of 100 m. The error induced on the SSI depends on the variation of these parameters within the pixel. The clearer the sky, the greater the error. Comparisons between ground measurements of hourly means of SSI made at sites in Europe less than 50 km apart for clear skies show that the spatial variation in SSI, expressed as the relative root mean square difference, can be greater than 10 %.

The main influence on direct irradiance comes from clouds, determined from pictures taken at a distance of 36 000 km. The distinction between different cloud types is very difficult. Observations made by satellite bear a spatial average over pixels; a satellite-derived information of 50% cloud cover for a pixel can result from a 50% semitransparent homogenous cloud or a broken cloud field with 50% cloud coverage within this pixel. These two cloudy conditions attenuate the radiation in a very different way.

Therefore, models have to make simplifying assumptions to transform the cloud information derived by the satellite into an effective cloud transmission. E.g. the transmission of direct normal irradiance is estimated with a simple exponential function depending on the cloud observations in the visible and infrared channels of the satellite. Figure 7.8 gives such a sample based on the visible cloud index. The applied function may not be the best for all sites and climatic conditions.

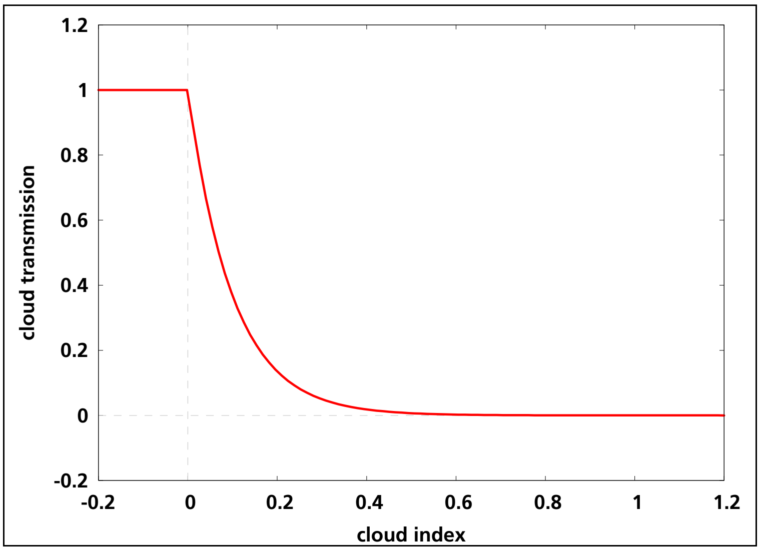


Figure 7.8. Example of transfer function from cloud observation (cloud index) to cloud transmission.

The variability in space and time has been reported in the scientific literature. For example, Wielicki and Welch (1986), Rossow and Schiffer (1999) note typical scale of variation of 30 m and 10 min. This is smaller than the spatial and temporal sampling in the Meteosat images: 3 km and 15 min.

8. Overview of the operation chains (workflow) in the present services SoDa and SOLEMI

The present services: SoDa and SOLEMI share the same method Heliosat-2 for converting satellite images into SSI as discussed in Chapter 6. They differ in workflow for computing irradiance products, i.e. the inputs, operations and their chaining.

The major reason for difference lies in their concept. The SoDa Service aims at delivering products in an automated manner with a large capability of dissemination (1000+ requests per day), while SOLEMI has been conceived to deliver products with a lower dissemination level.

Nevertheless, both workflows for computing irradiance products can be represented by the same schematic representation in Figure 8.1.

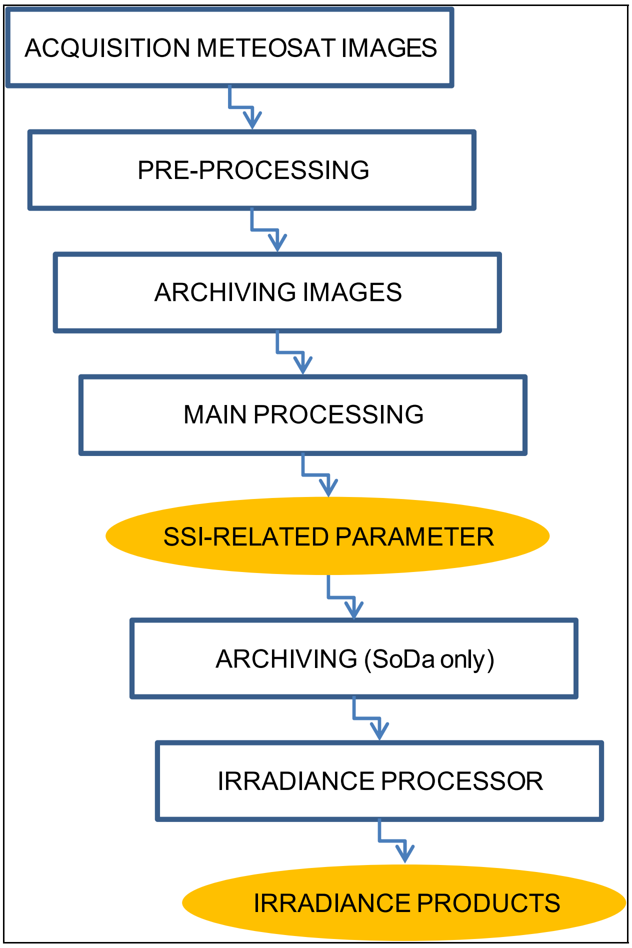


Figure 8.1. Schematic representation of the workflow of the SoDa and SOLEMI services for computing irradiance products

Meteosat images are acquired by the means of a receiving station. Pre-processing is performed as well as control of quality of images. These images are stored into a database. The main processing converts Meteosat images into images of a parameter that is related to the SSI in the Heliosat-2 method: the 15-min irradiation for SoDa and the cloud index *n* for SOLEMI. In the SoDa Service, the main processing is triggered automatically once an image received every 15 min. In SOLEMI, this processing is triggered only on request. The SoDa Service archives the clear-sky index. In both services, the irradiance processor is triggered on request and computation of irradiance products is performed on-the-fly.

The methods for computing irradiance products are presented in Chapter 6. They are not recalled here; the focus in this Chapter is on the operations and their chaining.

8.1. Overview of the workflow in the SoDa Service for producing irradiance products

Figure 8.2 displays a schematic representation of the workflow for producing irradiance products in the SoDa Service.

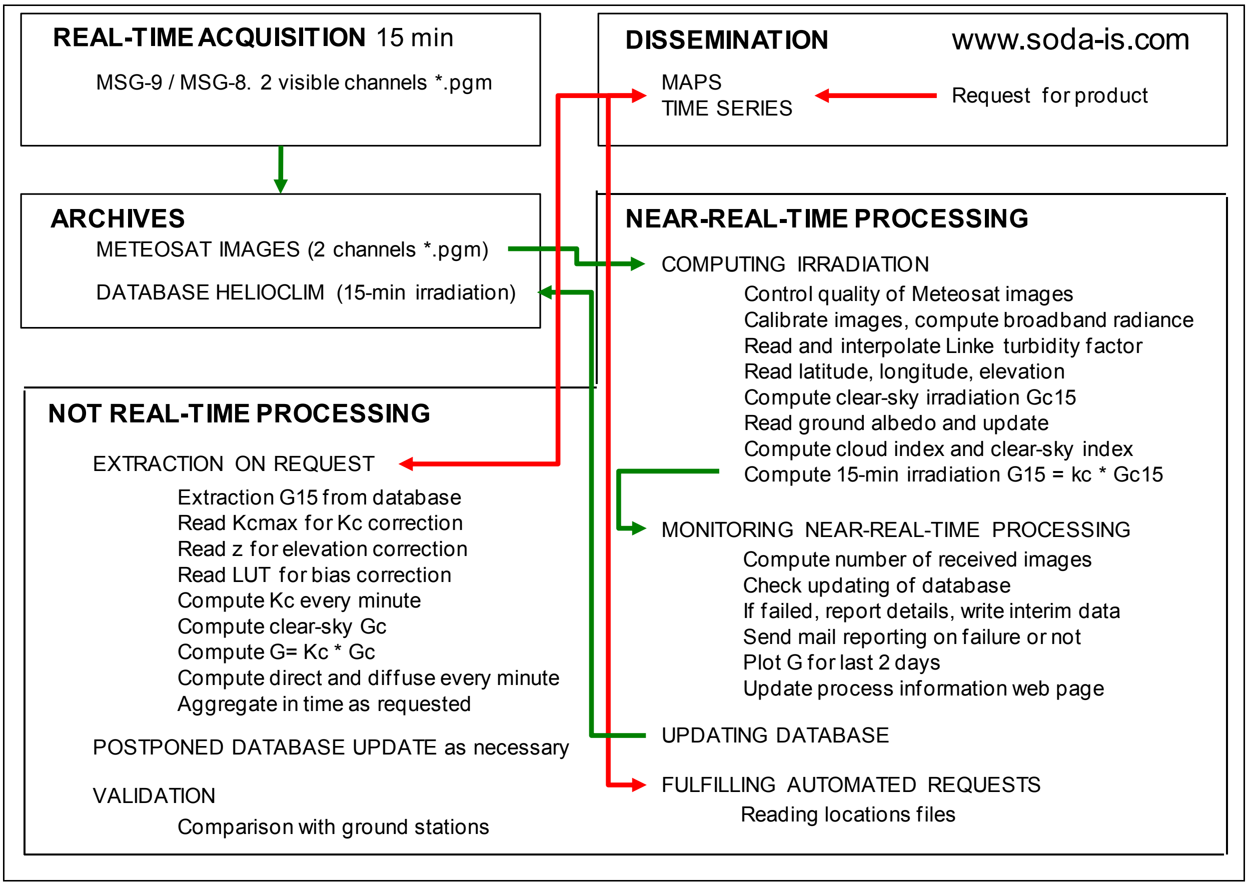


Figure 8.2. Overview of the workflow in the SoDa Service for computing irradiance products

Meteosat images are received every 15 min by a PC connected to an antenna. Only the two channels in the visible band are kept. The images are stored into a database.

The near-real-time processing is triggered at the end of the day by the reception of the last images at 21:00 UT. The first operation is the control of the quality of Meteosat images. It consists in looking for the missing lines if any and in the check of the position of extreme lines and columns in each image. If a failure is observed, the processing stops.

Meteosat images are calibrated using the calibration coefficients supplied in the flow emitted by Meteosat, resulting into two images of radiance every 15 min. These two images are then combined to create an image of broadband radiance (Cros et al. 2006).

Inputs to the method Heliosat-2 are the latitude, longitude, and elevation of the current pixel. Another input is the Linke turbidity factor characterising the optical state of the clear atmosphere. It is read from a database containing monthly values and interpolated for the day under concern. The clear-sky irradiation for the 15 min period is computed by the ESRA model, as explained in Chapter 6. Then, using a database of ground albedo, the cloud-index, then the clear-sky index, and finally the irradiation G15 for the 15 min period are computed. The irradiation is stored in the HelioClim-3 database.

There are a number of control points in the workflow for monitoring the smooth running of the near-real-time processing. Each time a failure is observed, detailed reporting is made to the management, written in a log file and sent by e-mail as well. A visual monitoring is in place to perform visually a gross check of the computed irradiance. It comprises a graph of the irradiances for the last two days for three selected sites: Sophia Antipolis where the chain is operated, and two extreme locations in the East and the West on the Equator. A Web page is updated that provides access to the archive of log files and graphs.

Request for products are made through the Web site of the SoDa Service (www.soda-is.com). There are two types of requests: manual and automated. Manual requests are made by the means of a browser. Automated requests are emitted by computers. They typically request for hourly values of irradiance every day for large numbers of geographical sites.

A request can be for a time-series (the standard product) or for a map. For the time-being, the processing is the same; a map is considered as made of independent pixels that are processed separately.

Multiple benchmarking activities demonstrated a few biases in the raw irradiation data contained in the HelioClim-3 database. A posteriori corrections are brought to the raw values. In order to cope with gaps and to compute direct and diffuse components, the clear-sky index is interpolated every minute. ESRA algorithms are used to compute direct and diffuse components from the global irradiance every minute. Finally, the 1-min values are summed up to yield the requested aggregation period, e.g. hour, day, month.

Automated requests are processed in the same way than the manual requests, except that their processing is part of the near-real-time processing and takes part immediately after the updating of the HelioClim-3 database.

Comparison between irradiance products and measurements at ground by well-calibrated instruments is made as often as possible. This is not systematic as the access to such data is limited. The results of such comparisons are used:

- to document the uncertainty in the retrieval displayed on the Web site,
- to set up a posteriori correction procedures if possible, to improve the quality,
- to detect possible flaws in the method or processing workflow, and correct them,
- to establish the model of uncertainty allowing to allocate uncertainty values to each irradiance value.

8.2. Overview of the workflow in the service SOLEMI for producing irradiance products

Figure 8.3 presents a schematic representation of the workflow in SOLEMI for producing irradiance products. There are several similarities in the operations with the SoDa Service.

Meteosat images are received by a receiving station at DLR. This station is external to the service SOLEMI and acts as a provider of images. Images are quality-controlled for all channels. They are then cut into overlapping tiles, which are stored into a database. This database is part of the DIMS system of DLR (Data Information and Management System). The SOLEMI service exploits data every 30 min for the Meteosat and every 15 minutes for the Meteosat Second Generation satellites.

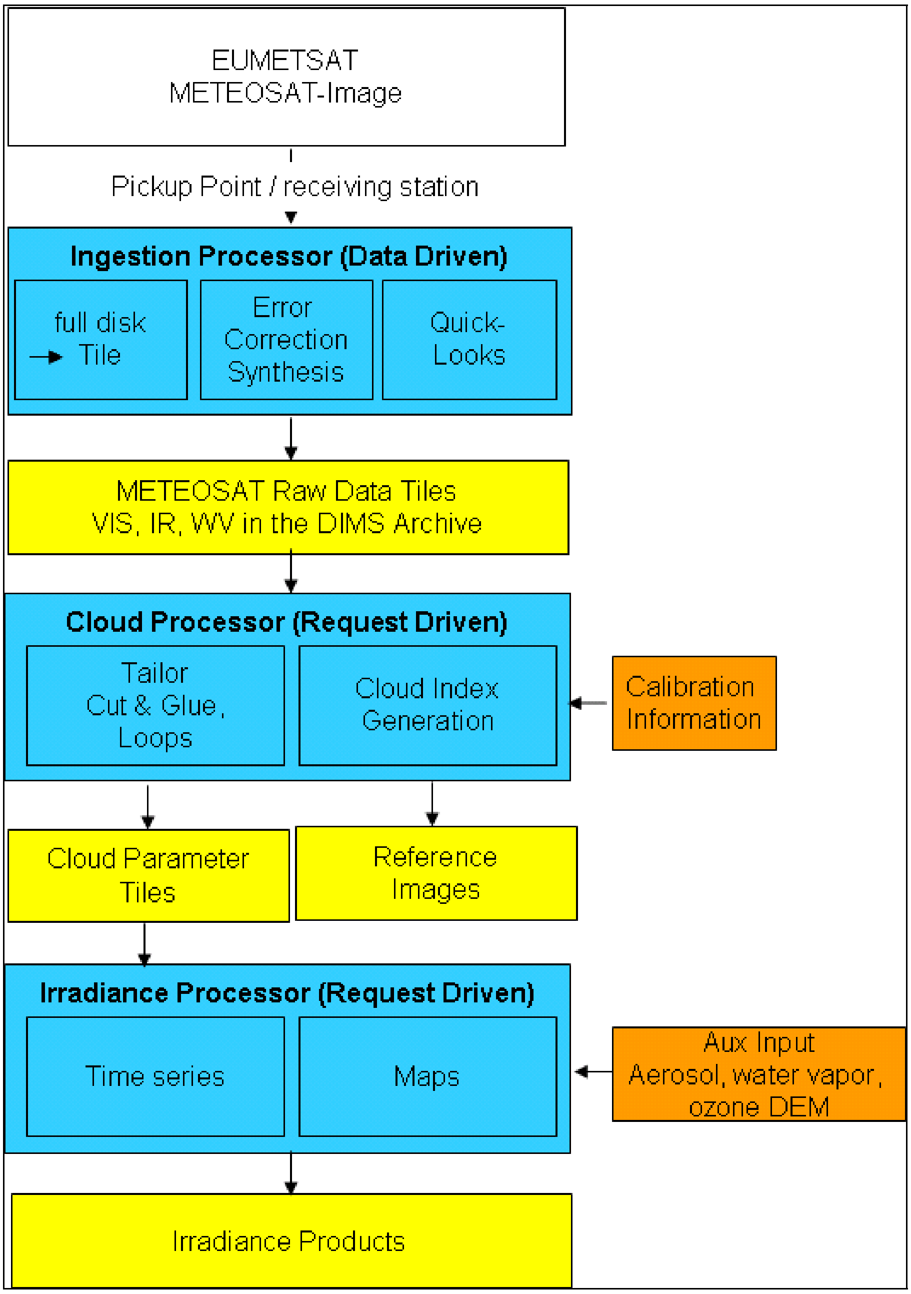


Figure 8.3. Overview of the workflow in SOLEMI for computing irradiance products

The processing to produce an irradiance product is made only on-request. Standard requests are for time-series for a given site, or for maps. As for the Soda Service, the processing for maps is the same than for a single site. Inputs are latitude, longitude, and elevation of the site of interest.

Meteosat images are extracted from DIMS and calibrated. The two images in the visible band are combined to create an image of broadband radiance (Cros et al. 2006).

Other inputs to the method Heliosat-2 in SOLEMI are the aerosol properties, the total water column, and the total column ozone. As explained in Chapter 6, these parameters are read from databases containing monthly or daily values and interpolated for the day under concern if needed. The clear-sky irradiance is computed by the Bird model, as explained in

Chapter 6. Then, using a database of ground albedo, the cloud-index, then the clear-sky index, and finally the irradiance are computed.

Products are created by aggregating irradiance values over the requested aggregation period, e.g., hour, day, month.

There are a number of control points in the workflow for monitoring the smooth running of the processing. Each time a failure is observed, reporting is made.

A manual inspection of the product is made based on scientific experience, taking into account the history available in the archive. Such procedures include comparing monthly means, e.g. all months of January in a period spanning several years, or comparing annual patterns and frequency distributions of single years against each other. If larger areas are processed a visual inspection of satellite raw data in movies is done.

Comparison between irradiance products and measurements at ground by well-calibrated instruments is made as often as possible. This is not systematic as the access to such data is limited. The results of such comparisons are used:

- to document the uncertainty in the retrieval displayed on the Web site,
- to detect possible flaws in the method or processing workflow, and correct them.

9. Transition towards the future operation chain in MACC-RAD

Setting up an operational information system with new capabilities and new processing methods is a lengthy process spanning over a few years. In order to exploit as soon as possible and efficiently the outcomes of the MACC project and other initiatives as they are flowing, a number of intermediate steps are being taken to implement these outcomes.

The MACC-RAD Service comprises the ensemble of the databases, means and operations to construct these databases, and means and operations to construct and disseminate the products. Progress is made in every aspect. This Chapter focuses on the improvements and changes that are planned to the current methods for computing the SSI, the databases and their construction, as well as the products and their construction. The dissemination part of the products is dealt with in the following Chapters.

Actually, it is too early to describe in detail many aspects of the transition chains and the operation chain in the MACC-RAD Service. An overview can be provided only.

9.1. Improvements and changes in the current methods and workflows

Recent initiatives from NCAR (USA, MATCH scheme) and the EU-funded project GEMS yielded to accurate assessments of optical properties of the aerosols with capability of producing daily maps. These recent results will be ingested in the SOLEMI workflow instead of the climatological maps described in Chapter 6. This should result in a better accounting of the day-to-day changes in aerosol properties. Comparison with ground measurements will confirm the improvement. This will be the first step in the transition process. The change in workflow should be small.

MACC will produce aerosol properties using a method similar or enhanced if compared to GEMS. Therefore, the expertise gained with these GEMS products will be efficiently used in the MACC-RAD Service.

In the meantime, other parameters such as the column content in water vapour or ozone are available daily over the world. MACC is producing such parameters as well as other sources. In the same manner than for the aerosol properties, these recent results will be ingested in the SoDa workflow instead of the climatological maps described in Chapter 6. This should result in a better accounting of the day-to-day changes in irradiance. Comparison with ground measurements will confirm the improvement. This will be the second step in the transition process. The change in workflow should be small.

The availability of these atmospheric parameters as well as the increase in computing power advocate for an increase in the complexity of the models used to compute the clear-sky models, which should result in an increase in accuracy. Such a model is being developed, called McClear. Inputs to this model will be outputs from MACC, except for site coordinates, solar angles, elevation, atmospheric profile, and ground albedo. The third step in the transition process is made of the development of this model and its validation.

The McClear model will be then integrated in the SoDa workflow for producing irradiance. The current ESRA model will be replaced by this new model. This will be a major step towards the operational MACC-RAD Service. It will lead to major changes in the workflow though it is too early to provide details. More accurate assessments of the irradiance under clear-sky are expected by this transition chain. It will also imply a series of validation exercises and the development of new models of uncertainty. This will change all procedures described in the box "NOT REAL-TIME PROCESSING" in Figure 8.2 describing the workflow in the SoDa Service.

9.2. Overview of the new method Heliosat-4

The new Heliosat-4 method is based on the principle that the SSI *I* for a cloudy atmosphere can be considered as equal to the product of the irradiance *Ic* obtained under a clear sky and a function *f(cloud, albedo)* modelling the extinction of the radiation by clouds and the contribution due to the ground albedo:

$$I = Ic\ f(cloud, albedo) \qquad (9.1)$$

This relation is very interesting for practical reasons, in particular for rapid calculations. Each part of the equation can be processed following the available spatial and temporal resolutions of their inputs. This relation also allows for the modular development of methods for computing SSI. Several options can be adopted for each model. A few of them were tested by Oumbe et al. (2010) in a preliminary study.

The possibility of considering several spatial and temporal resolutions is of practical importance in MACC. MACC outcomes should be daily values or every 3 h but by no means every hour. The expected spatial resolution should be in the range 50 km - 200 km. The cloud properties can be derived from the processing of Meteosat images as done by DLR with the adapted APOLLO chain. Such products will be available every 15 min for each Meteosat pixel.

Figure 9.1 displays a schematic view of the method Heliosat-4. The method will exploit the model McClear. Radiative transfer in clouds may be modelled by the Delta-Eddington approximation.

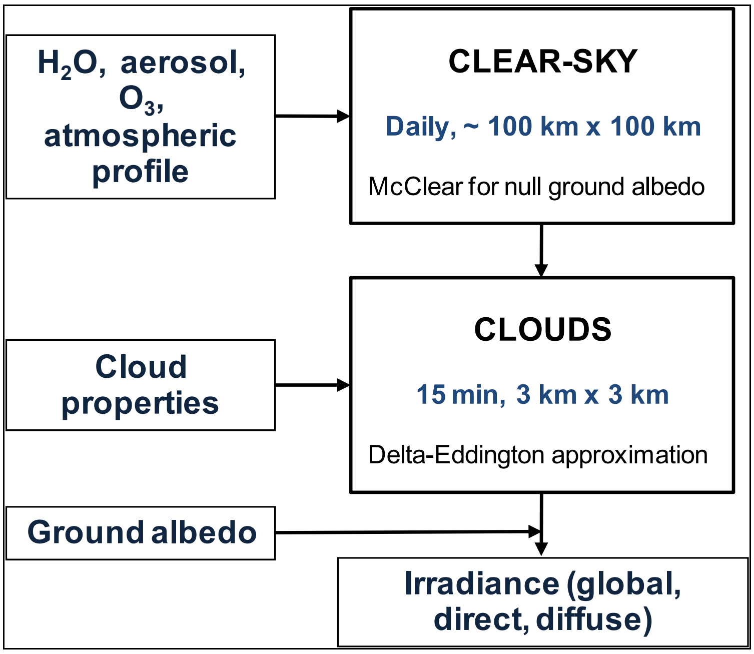


Figure 9.1. Schematic view of the Heliosat-4 method

9.3. Overview of the workflow in the future chain

The adoption of the method Heliosat-4 leads to an entirely new workflow for producing irradiances. This workflow could be sketched by Figure 9.2 though it is too early to provide details. This overview does not comprise all elements as in Figures 8.2 and 8.3 for the services SoDa and SOLEMI.

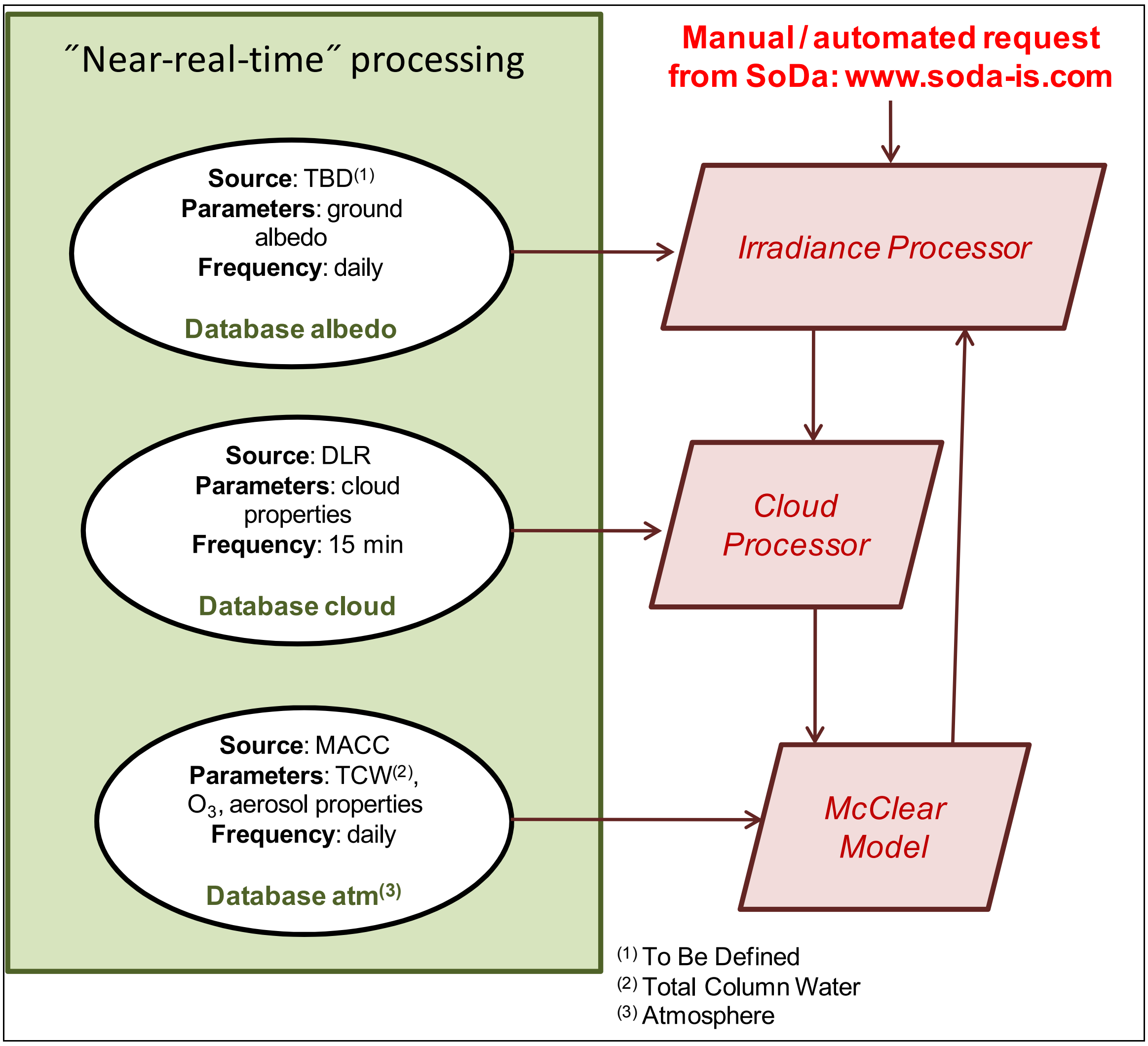


Figure 9.2. Schematic representation of the workflow of the MACC-RAD Service for computing irradiance products. The three databases are part of the database HelioClim-4.

Several data will be received from various sources: MACC, DLR and a yet-to-be-defined for ground albedo. These data will be pre-processed and stored in several databases. These intermediate databases (or tables) will constitute the HelioClim-4 database.

The delivery deadline from each source is still unknown. It could amount to several days. Therefore, the term 'near-real-time' has to interpreted as within 24 hours (preferably) or longer. Operations are triggered by successfully received input data sets.

Currently, the concept to produce products is that the processing is made on-request (on-the-fly). When a request is made for a time-series for a given site and a given period, the irradiance processor will invoke the McClear model with inputs extracted from the database "atm". Extinction coefficients are then obtained by the cloud processor using inputs from the database "cloud". Finally, the contribution to the diffuse irradiance due to the ground albedo is computed.

Tests have been made that demonstrate that such an on-the-fly processing is sustainable in the perspective of the MACC-RAD Service. Nevertheless, it is likely that databases of irradiance will be pre-computed, at least to best answer to request for maps of daily or monthly values of irradiance.

9.4. Quality control of products

A quality control must be performed everyday by comparing the core products to measurements performed by ground stations and to re-analyses. The first aim of this quality control is to monitor possible trends in products and decide for appropriate corrections. In that sense, what is important is the change of differences between products and measurements or re-analyses with time outside the expected range of variation. To do so, a model should be available that explains these discrepancies as a function of known explanatory variables such as the solar zenithal angle or the temporal variability of the SSI. Therefore, the distance between products and re-analyses can be predicted. It will be used to monitor the quality of products: large values should indicate suspect products.

The second aim of this quality control is to perform a benchmarking of the products against a reference. This can be done only with quality-proven measurements. By comparison, one will obtain the uncertainty parameters synthesizing the difference between products and reference following the methodology recommended by the projects IEA SHC 36 and MESoR. These uncertainty parameters will be displayed on the Web pages of the MACC-RAD Service to support the documentation on the quality of products.

Based on the results of such comparisons, a model of uncertainty can be established or improved that provides for any instant the plausible uncertainty level of the SSI, given known explanatory variables.

To perform the quality control, operations should be established to collect in an automatic way re-analyses values from ECMWF and ground measurements from selected sites or from the World Radiation Data Center. Quality control procedures must be also implemented that apply onto these measurements and re-analyses.

PART C. DELIVERING PRODUCTS

10. Core products

The definition of the core products may evolve for various reasons. A value-added product may one day become a core product, depending on advances in science and technology. The data policies of MACC and of the GMES Atmospheric Service should be taken into account in the definition of the products. These policies include the important issue of financing and therefore of the cost of the products to customers. Combined together with others, these elements cast shades on the definition of the products. The proposed description is tentative and will be refined as the MACC data policy will become clearer.

Presently, there are two series of products in the MACC-RAD Service:

- ARCH products: the first series is an archive: 1984-2005, based on Meteosat First Generation (MFG) data. It is denoted by the letters ARCH (for Archive),
- MSG products: the second series is based on Meteosat Second Generation (MSG) series of satellites, starting from 2004 and on-going. It is denoted by the letters MSG.

A third series will be incorporated later as Meteosat Third Generation series of satellites will become available.

For both series currently available, core products in the MACC-RAD Service are time-series of solar radiation available at ground surface, also called surface solar downward irradiance (SSI).

There are three irradiance parameters identified as necessary by users. Table 10.1 provides a definition of these parameters that are contained in the core products.

Acronym	Definition
GHI	Total global irradiance, i.e., the SSI integrated over the whole spectrum available at ground level, on a horizontal surface
DifHI	Total diffuse irradiance, i.e., the diffuse part of the SSI integrated over the whole spectrum available at ground level, on a horizontal surface
DirHI	Total direct (beam) irradiance, i.e., the direct part of the SSI integrated over the whole spectrum available at ground level, on a horizontal surface

Table 10.1. Definition of the surface solar downward irradiance (SSI) parameters contained in the core products

10.1. Main features of the core products. Geographical and temporal coverage

Table 10.2 summarizes the geographical and temporal coverage of the core products.

	Europe / Africa / Middle East / Atlantic Ocean	Central Asia / Indian Ocean
ARCH	1984 – 2005	1995 - 2005
MSG	Since 2004	No

Table 10.2. Geographical and temporal coverage of the core products

The main features of the core products are presented in Table 10.3.

	ARCH	***MSG***
Type of product	Time-series	
Best temporal resolution	1 h	15 min
Spatial resolution	Spatial resolution is the original pixel of the Meteosat image. Approx. 3 km at satellite nadir, and 5 km at mid-latitude	
Parameters	GHI, DifHI, DirHI	
Processing	On request	Near-real-time
Update of the database	End of month	End of day

Table 10.3. Main features of the core products of the MACC-RAD Service

10.2. List of products

Within each series of products ARCH or MSG, there are several products delivered by the MACC-RAD Service. They differ by the temporal aggregation. The main features remain similar.

The period of integration is defined as the time during which the solar radiation is integrated to yield period-averaged irradiance. For example, an integration period of 1 h means that the delivered irradiance is the hourly mean of irradiance during one hour. Following meteorological standards, the time given for an irradiance value is the end of the integration period. For example, the value given for 11:00 means an integration period from 10:00 to 11:00 if the period is 1 h, or 10:30 to 11:00 if the period is 30 min.

This list of products results from request by users. It may evolve as the needs of users evolve. Table 10.4 lists the products derived from the Archive (ARCH). Table 10.5 lists those from MSG-based products (MSG).

A product contains the three irradiance parameters: GHI, DifHI, andDirHI, listed in Table 10.1.

Product name	Integration period
ARCH.1h	1 h
ARCH.1d	1 d (1 day)
ARCH.1m	1 mo (1 month)
ARCH.1y	1 y (1 year)

Table 10.4. List of the core products based on Archive (ARCH)

Product name	Integration period
MSG.15min	15 min
MSG.1h	1 h
MSG.1d	1 d (1 day)
MSG.1m	1 mo (1 month)
MSG.1y	1 y (1 year)

Table 10.5. List of the core products based on MSG-based irradiances (MSG)

10.3. How to make a request for a MACC product

Requests will be made through an information system which is described in the next Chapter. For the time-being, there is the possibility of using the Web SoDa Service which is well-known in the solar radiation community which uses it intensively.

The Web SoDa Service is actually a precursor of the future MACC-RAD Service as discussed in Chapter 11. It already offers an access to the MSG-derived database HelioClim of irradiance, discussed in Chapter 5. There are two major differences between the HelioClim products and the foreseen MSG products from MACC. Firstly, they differ in definition: the HelioClim product is only GHI. Secondly, the access to HelioClim products is made on commercial basis, while the status of MACC-RAD products is unknown in this respect.

Nevertheless, these differences can be removed to produce an interim version of the access to the MACC products.

From a practical point of view, and beyond the various issues related to being a recognised customer of the information system, the inputs by users needed to trigger a request for a selected MACC product will be:

- the geographical coordinates of the site of interest, or the name of this site,
- the elevation of this site above sea-level. By default, the application uses well-known digital elevation models, such as NASA-SRTM,
- the period of time: begin data, end date.

10.4. Delivery deadline

Delivery deadline is the time lag between the moment the request is made and the instant of delivery. The delivery deadline depends on the series of products: ARCH or MSG.

The ARCH products are computed on request and are not available as such on the shelf. Once the request for a product is made, DLR, the author of the products ARCH, selects the best suitable auxiliary data set for the site among global atmospheric data sets (aerosol, water vapour, ozone) from different earth observation sources and climate models. The atmospheric data is gridded to a resolution of 1°x1° and the cloud data from Meteosat has a nominal resolution of 2.5 km x 2.5 km at the sub satellite point. The geographical coordinates (latitude, longitude and height above sea level) in decimal degrees and meters have to be delivered to DLR. The product is delivered per e-mail within two weeks.

The MSG products are computed on-the-fly from the database HelioClim. The request is made through the Web site of the SoDa Service (www.soda-is.com) and the answer is provided within a few minutes.

Access to the most recent data is governed by data policy. It depends also on the delivery deadline for availability of the inputs to the method used to compute the irradiance.

The description above stands for the current situation. It will evolve as the situation evolves from interim to final solutions.

10.5. Data policy. Conditions of use

As said before, the data policy of MACC products is still an open issue. The MACC-RAD products will follow the rules established as soon as they become available. In addition, the data policy of Eumetsat shall govern the use of Meteosat data to produce the MACC-RAD products.

The principles governing the conditions of use are that the customer assumes all the responsibilities for the use of the provided data, especially concerning:

- the fitness-for-purpose of the data to the needs of the customer,
- the use of the data,
- the qualification and expertise of the staff of the customer regarding such data.

The MACC-RAD product is supplied "as is". The author and provider disclaim all warranties, expressed or implied, including, without limitation, the warranties or merchantability and of fitness for any purpose. The author and provider shall in no event be liable for indirect damages such as loss of profits, loss of markets, loss of clientele, commercial injury or disturbances, brand-image impairment or unfair-competition suits, or other consequential, incidental or special damages in connection with the MACC-RAD products.

The customer acquires a license for the use of the MACC-RAD product. It does not bear any rights upon the products themselves.

For the time-being, the data policy for both ARCH and MSG products is on a commercial basis. The French company Transvalor, a subsidiary of Armines, is taking care of the commercialisation of the database HelioClim through the Web SoDa Service.

10.6. Format of products

10.6.1. Current formats

Two formats are provided for the currently available products: CSV (comma-separated values) or Excel, and HTML.

The HTML format can easily be ingested by copy-and-paste tools into spreadsheet or text files. Excel files are suitable for use by the Microsoft or OpenOffice suites. Text files or CSV files are easy to handle by tools such as Matlab or proprietary applications written in any language (e.g., C, PHP, Python…).

Metadata are available to describe the MACC-RAD products in GEOSS-compliant portals. These are *discovery* metadata that permit the cataloguing of these products and therefore to users to discover the products. These metadata obey to INSPIRE implementation rules (Ménard et al. 2009).

The MACC-RAD products are organised as lines of values (columns). Before the first line of data, there is a set of metadata for exploitation of the data. These metadata are written as text in the delivered file. For the time being, they do not obey any standard. They describe what are the various elements contained in a product. Currently these metadata are:

- *title*: title of the time-series, e.g., "HelioClim-3 Database of Solar Irradiance v2 (derived from satellite data)",
- *provider*: name of the provider, e.g., "MINES ParisTech - Armines (France)",
- *site latitude and longitude*: geographical coordinates of the site,
- *elevation*: elevation above sea level in m,
- *beginning and end dates*,
- *summarization*: period of integration, e.g., 15 min.
- *time reference*: time system used: Universal Time (UT), or True Solar Time (TST). This is present only when the period of integration is less than 1 d.

In addition, each column has a label. Each label is defined in the metadata. For example, the irradiance data will be found in the column labelled "Irradiance". The metadata contain the following text "Irradiance (W/m2): Irradiance averaged over the period (-999 if no data)". In this example, one notes that the unit of irradiance is mentioned as well as the value meaning that no data is available.

Each line corresponds to an instant of observation. To ease the exploitation, the instants of observation are regularly spaced. For example, a product of hourly values will comprise 24 lines per day, even if several lines exhibit null irradiance because of the night.

The typical content of a line is:

- instant of observation,
- irradiance value, e.g., GHI,
- uncertainty attached to this irradiance,
- reliability code,
- irradiance at top-of-atmosphere,
- irradiance that would be typically observed if the sky were clear.

The exact content of a line depends on the type of product and this is why the metadata are included in the file. For example, there is a column "day" for products containing daily values, which does not exist in products containing monthly values.

The meaning of the reliability code depends on the type of products. This code denotes whether the value results from a time interpolation (case of 15-min or 1-h values), or provides the number of valid 15-min values used to compute a daily average, or the number of valid daily values used to compute a monthly average. This is fully described in the exploitation metadata conveyed by the product.

The uncertainty can be expressed as a single value, e.g., standard-deviation, or as lower and upper bounds. These bounds are such that there is a 68% chance that the actual value is comprised between lower and upper bounds.

10.6.2. More standard metadata for exploitation in next steps

In a next step, the format of the products will contain metadata for their automatic exploitation by other applications. These metadata for exploitation are conveyed in the products themselves. The supply of a product thus provides both the data and the explanations (metadata) to exploit the data in an automatic manner.

These metadata will be INSPIRE and GEOSS-compliant. A first application schema was developed by the international community on solar resource knowledge (Gschwind et al. 2007b). This schema helps to develop web services that are interoperable, i.e., that can exchange information with various portals and other web services.

Below are presented the major elements of the schema "SolarResourceKnowledge-2.1.xsd", Version 2.1, dated February 2009 and available at www.soda-is.com/schemas/index.html. This schema is in place in the information system set up in the projects MESOR and IEA SHC 36 and described in Chapter 11.

geopoint. A *geopoint* is defined by a latitude, longitude and elevation above sea level.

IPR. An *IPR* comprises several elements to describe the property rights attached to the product:

- *providerName*: name of the provider,
- *copyrightText*: a free text describing the rights and conditions of use,
- *providerURL*: the URL pointing to the appropriate part of the Web site of the provider,
- *providerLogoURL*: the URL pointing to the logo of the provider.

SpectralRange. A *SpectralRange* comprises several elements describing a spectral interval:

- *begin*: beginning wavelength,
- *end*: end wavelength,
- *FWHM*: full width at half maximum,
- *unit*: unit of the elements above.

tiltedPlane. A *tiltedPlane* comprises several angles describing a tilted plane:

- *tilt*: the tilt angle,
- *azimuth*: the azimuth angle
- *unitAngle*: the unit of the above angles.

singleObservation. A *singleObservation* describes a single observation by the following elements:

- *date*: instant of observation, using ISO8601, e.g., 2008-25-01T18:43:26,
- *value*: the value of the observed parameter,
- *uncertainty*: the uncertainty attached to this observation,
- *reliability*: the reliability of this observation.

sequenceOfObservation. A *sequenceOfObservation* describes a time-series of single observations by the following elements:

- *observationType*: observed parameter, e.g., global radiation,
- *IPR,*
- *geopoint,*
- a series of *singleObservation,*

- *timeSeriesTitle*: a title of the time-series,
- *unitUncertainty*: the unit for uncertainty,
- *duration*: duration of the integration period, defined as ISO8601, e.g., P1M for 1 month,
- *absenceOfValue*: the value denoting the absence of value, e.g., -999,
- *unitOfMeasure*: the unit for the *value* in *singleObservation*.

sequenceOfRadiationObservation. A *sequenceOfRadiationObservation* describes a time-series of irradiance, possibly observed on a tilted plane. It extends *sequenceOfObservation* and comprises the following additional elements:

- *spectralRange,*
- *tiltedPlane.*

10.7. Maps

Maps are not part of the MACC core products. Nevertheless, as the requests for maps are regularly made, it is worthwhile mentioning that both Armines and DLR can deliver digital maps on request by exploiting the core products.

These digital maps contain yearly or monthly irradiation (global on horizontal plane and/or direct on plane normal to sun rays). These values are averaged over several years, depending on request. The maps delivered by Armines are based on the MSG-based products; those delivered by DLR are based on the Archive and MSG-based products. Other parameters can be delivered in addition, such as frequencies of values exceeding a threshold.

The digital maps are made of grid cells, which are squared by default. Smallest cell size is presently 30 arcsec, i.e., approximately 1 km at mid-latitude. The elevation (altitude) of the cell is taken into account to compute the irradiation; the elevation is provided by digital elevation models, such as NASA-STRM, or GTOPO30. Larger cell sizes are possible, as well as rectangular cell size.

The digital maps are delivered in various formats that can be ingested by GIS software (geographical information system). The data may also be delivered as Google Earth overlay (kmz-file) or as pdf.

11. Description of the future MACC-RAD Service

The following is a preliminary version of the description of the future MACC-RAD Service. There are a large number of unknowns in the future of the GMES Atmospheric Service. Given these uncertainties, we can only propose a tentative description.

The MACC-RAD Service comprises the ensemble of the databases, means and operations to construct these databases, and means and operations to construct and disseminate the products. The current databases, their construction, the products and their construction have been already described. This Chapter focuses on the dissemination part of the products.

Given the experience gained by several precursor services delivering databases and applications relating to solar radiation, and given the large penetration rate of the current SoDa Service, we propose to connect the MACC-RAD Service to the SoDa Service for a better dissemination.

In the following, we introduce the concepts of collaborative information systems and web services. Then, we describe the prototype of information system established by two international initiatives. The new generation of the SoDa Service will be built on this prototype, and, consequently, the future MACC-RAD Service. Therefore, it is worthwhile introducing the structure and tools of this prototype and to present briefly its use.

11.1. Introduction to collaborative information systems and web services

The collaborative information system aims at providing an easy access to various services (databases, data sets, applications) in a homogeneous and seamless way. It is a one-stop shop where users find the requested information. Whatever the service, the user interface is more or less the same and consequently, very familiar. The delivery means is the same, i.e., by means of the Web. The format of the outputs obeys also some standardization.

It is not exactly a portal which displays links to providers of services. Here, in the SoDa information system, the providers are "hidden" in the sense that though they are known to users of course, users do not access directly to their own web sites. Users only interact with the information system, i.e., one web site, and the information system plays the role of a broker.

Figure 11.1 is a sketch of the structure of the collaborative information system. It describes the actors: customers, broker, providers of services, and their relationships. The broker is offering a unique access to an ensemble of services supplied by providers. The broker is taking care of the relationship with its customers on the one hand, and with its providers on the other hand.

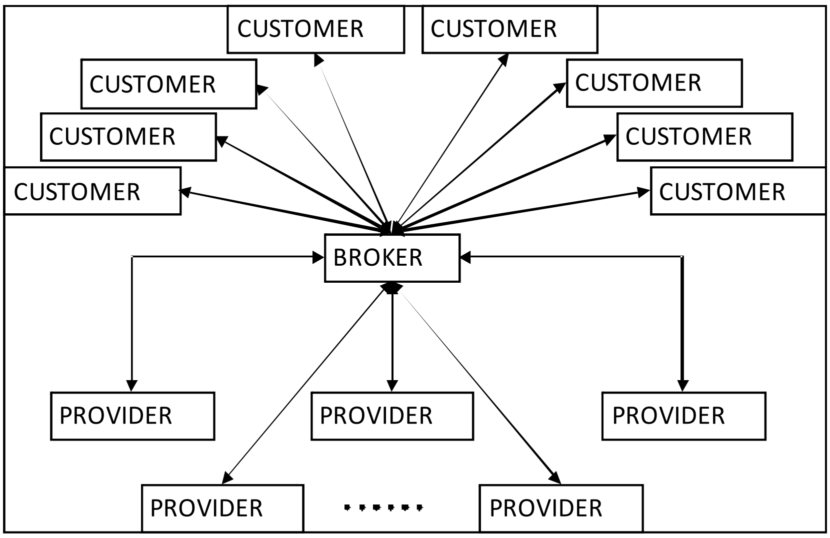


Figure 11.1: Sketch of the structure of the collaborative information system

The benefit of these collaborative systems is that they collect data and call upon other applications to answer as best as possible to the request. In doing so, the broker does not centralize the data into a warehouse nor write the software for applications. It concentrates on the best ways to satisfy the request of the customers and to select the most appropriate services. From the point of view of providers, the benefit is to keep hand on their data and applications. The provider does not need to send its data to a centralized database or data silos nor install its applications on a remote computer belonging to the broker.

The collaborative information system offers several advantages, ranging from immediate availability of new data or latest version of an application to the customers, to less restrictive agreements on intellectual property rights between the broker and a provider. From the point of view of customers, it offers a one-stop shop where to find information necessary to the accomplishment of their tasks and easy to use and reach because it is based on the Web.

According to Cros and Wald (2003), a collaborative information system, or co-operative information system, benefits from the advanced information technologies. Such an information system is essentially based on interactivity between different web servers with an information-delivery system calling on other servers that provide the necessary weather data and other information (e. g., topography, hardware properties, costs...).

An excellent example of a mature collaborative system in the field of solar energy is the SoDa Service[3]. It realizes an integration of information sources of different natures and located in various institutes and companies in the world within a smart network on the Web (Gschwind et al., 2006). These sources include databases containing solar radiation parameters. Other relevant information are also available, such as other meteorological parameters: surface air temperature, relative humidity, forecasts, Linke turbidity factor, astronomical parameters, or digital elevation models. Several of these databases originate from an advanced processing of remote sensing images, especially those about surface solar irradiance or daylighting.

All these databases are maintained by different institutes and companies. Before the advent of the SoDa Service, several of them were already available on the Web but separately, while others were not. The SoDa Intelligent System builds smart Internet co-operation between sources (Wald et al., 2002, 2004). By this means, all databases are available within the same Web site: one-stop shop, and in a standardized manner. In addition to databases,

3 www.soda-is.com

the SoDa Service offers access to application-specific user-oriented numerical models and advanced algorithms. These applications are hosted by various institutes and companies, and here again, the SoDa Intelligent System builds link between one or more applications and the databases that are necessary as inputs (Gschwind et al., 2007a).

In collaborative systems, the various sources of information: databases, data sets, maps, applications,…, are called services. In the SoDa information system, these services are actually Web services, in the sense of the World Wide Web Consortium, meaning that they are applications that can be invoked on the Web and that the basis of the network is the Web. As far as databases and data sets are concerned, the service is the application that retrieves data from the database.

Figure 11.1 gives a clue about responsibilities. The broker has the responsibilities for making customers and itself respect the terms and conditions under which a provider accepted to supply information to the broker. The provider has the responsibilities of the quality and ownership of the information it supplies. The customer is granted a license of usage of information and should respect it. In any case, the property rights belong to the creator of the information.

Figure 11.1 also shows the middleware infrastructure, schematized by the arrows, that enables the exchange of information. Besides it, are hidden the metadata that are a key element for facilitate access to information in a seamless way as well as standards for exchange on the Web (e.g., HTTP, SOAP).

11.2. The MACC-RAD Service and the SoDa Service

The basic concept of the MACC-RAD Service is the following:

- connect to a collaborative SoDa Service, built on the most advanced Web technologies and free software. Among other advantages, it permit to connect immediately to other already available databases and other sources, as the SoDa Service is GEOSS-compliant;
- MACC-RAD Web services are deployed to disseminate the products;
- these Web services are exposed in the SoDa Service. Therefore, the MACC-RAD Service acts as a provider (Fig. 11.1);
- the Web pages permitting to invoke the MACC-RAD Web services should bear clear references and links to MACC and the GMES Atmospheric Service as a whole. The look should recall the identity of the MACC pages;
- the legal agreement with the broker should be in line with the MACC policies on data dissemination and intellectual property rights.

The commercial aspects are not discussed here as the MACC data policies and the GMES data policies are still under discussion. Nevertheless, we have considered several of them in the design of the system. The selected tools offer means to manage communities of users with different access rights and tools for the monitoring of the system. It is possible to operate on a discriminatory basis for access to products. It may be possible that access may be restricted to a few products or depending of the requested volume of data, and means are available to manage such restrictions efficiently and in a transparent way.

Means should be established to monitor the use of the MACC-RAD Service. At least, this would show how much the products are used, where and when. Actually, it would permit to establish strategy for a more efficient service. In particular, this would help in future versions of the service by, e.g., permitting a faster access to the most used products, establishing typical profiles of users and thus presenting products in a more relevant way, or in defining new products, e.g., a combination of products or an archive containing several products in one click instead of several.

It is worthwhile mentioning that in adopting this concept, the MACC-RAD products are disseminated under the form of Web services that are compliant with current Web standards, including those in force in GEOSS. This means in particular that the MACC-RAD products can be exposed not only on the SoDa Service as proposed, but also on other portals more related to the Earth Observation, including the GEOSS portal. This increases strongly the potential in dissemination.

11.3. The middleware and related tools

The middleware is an important element in the collaborative information system. It is a means to unify and ease access to solar resource information. The project MESoR (Management and Exploitation of Solar Resource Knowledge) funded by the European Commission, from 2007 to 2009[4], and the Task SHC 36 of the International Energy Agency[5], working together have built a prototype of the collaborative information system upon the existing knowledge and precursor Web services, and more specifically on the knowledge gained by the SoDa Service, and adopting interactive mapping and analytical features from the PVGIS[6] portal.

The original SoDa portal was built with proprietary software and communication protocols. Taking into account the fast pace of development of the Web, MESOR and Task SHC 36 decided to build a new portal, using open source software with support from a large development community and standardized Web services. This makes the new portal more sustainable in terms of software development, and the connection to the portal easier and more open as only widely accepted standards are followed.

Metadata are essential to exchange knowledge between applications. They describe objects to be exchanged (e.g., a time series of irradiance, a geographical location, a date…). After a series of consultations with several bodies involved in standards, such as ISO, GEOSS (Global Earth Observation System of Systems), INSPIRE (Infrastructure for Spatial Information in Europe) and national meteorological offices, a thesaurus has been defined which is specific to solar resource. A thesaurus is a set of terms that describe the solar resource. Together with the thesaurus, a series of tags is defined in the XML language for the practical implementation of this thesaurus: the Schema. A file is constructed that contained this series of tags and can be read by a computer; its extension is .xsd that stands for XML Schema Definition. A first version of the thesaurus was written in 2007 (Gschwind et al. 2007b). A revision was published in September 2008[7] and briefly presented in Chapter 10.

In the prototype of the information system, other schemas are used for describing e.g., the time and dates. INSPIRE and ISO standards are used in these cases. Among them, are the description of the intellectual property rights.

Figure 11.2 presents a diagram of the components and data flows in the information system. This diagram is shared in two parts by a dashed line. The left part deals with the broker (middleware); the right part shows an example of a Web service provided by a remote web server (the provider). The box "metadata" at the bottom recalls the essential role played by metadata in exchange of information.

4 http://www.mesor.org/
5 http://www.iea-shc.org/task36/index.html
6 http://re.jrc.ec.europa.eu/pvgis
7 available at http://www.soda-is.com/schemas/index.html

The numbers in circle describe the data flow, following a request made by a customer. After accessing the Web portal, the customer selects a service in a catalog (1). This catalog of service is one of the portal components. This selection triggers another series of components: the Service Invoke Components. A GUI (Graphical User Interface) appears (2) and the customer fills in a form defining the inputs to the requested service, e.g., first and last dates of a period of time, geographical coordinates…

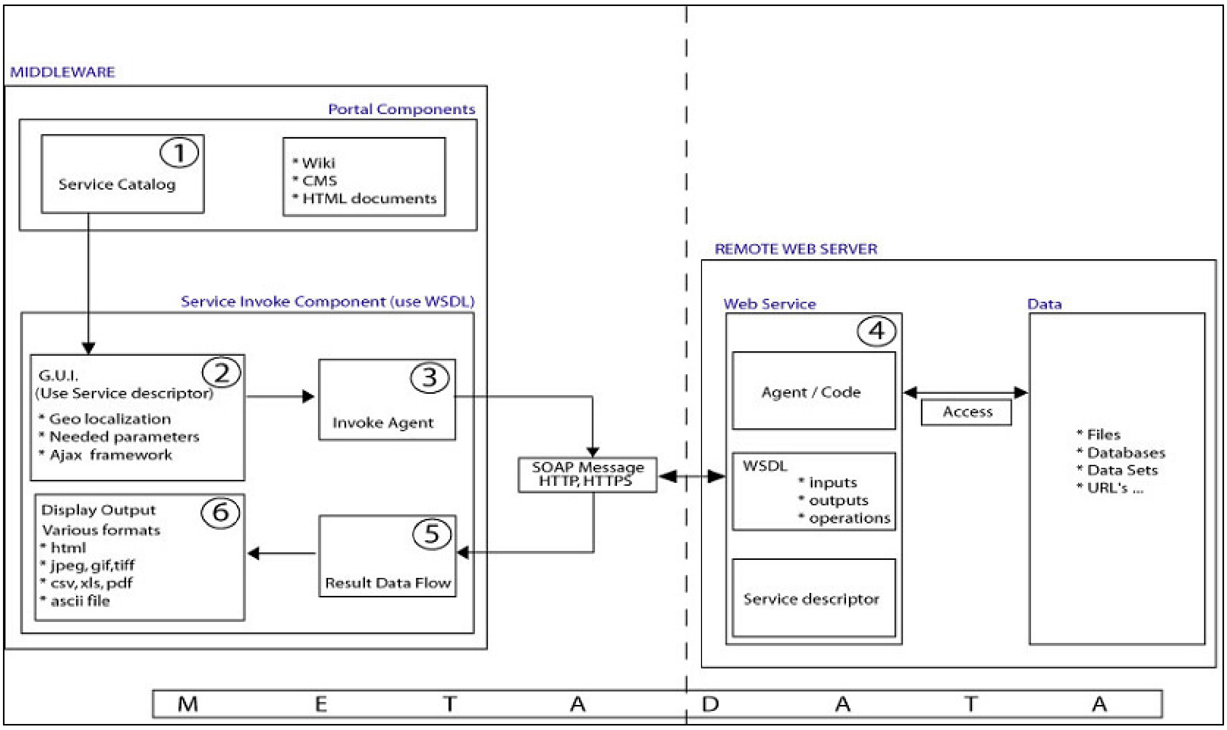


Figure 11.2: Diagram of the components and data flow in the information system

Once the form completed, the customer clicks on a button to obtain the requested data. This triggers the "Invoke Agent" (3) that submits the request to the remote server. The request is encoded following standards: SOAP and HTTP. The remote web server accepts the request and invokes the Web Service (4). This web service may access other resources belonging to the provider or not, under the responsibility of the provider. At this specific point, there is no need that the data of the provider is described in a standard format; it can be in a proprietary format. The provider returns the requested data, also encoded with SOAP and HTTP protocols. Part of the requested data describes the intellectual rights of the provider.

The broker accepts the returned data (5). It formats these data for their presentation (6). Different types of presentation are possible, such as tabulated data for HTML display in the customer's browser or data in Excel files. This also includes the display of the intellectual property rights of the provider.

The general scheme for data flows follows the scheme already experienced in the SoDa Service (Gschwind et al. 2006; Wald et al. 2002, 2004). The major conceptual differences are the use of standards (XML, WSDL) instead of a XML Schema specific to the original SoDa Service, and the fact that the formatting of the returned data is performed by the middleware in this prototype while in the original SoDa Service, it is performed partly by the provider, partly by the middleware.

The projects MESoR and Task SHC 36 made a lot of efforts to build on existing software and tools that are freely available. It also tries to minimize the amount of efforts to be done by a provider to offer a Web service.

The databases, data sets, applications… belonging to a provider remain at the provider's premises as already mentioned. The provider does not have to use international standards for the format of his data, nor has he to transform the original format into another one. In this concept, the Web service ensures the interface between the data and the middleware. Web services are a standard mean to expose and consume local or remote data. This offers several advantages. On the one hand, the providers keep the overall control of their Web services. On the other hand, the customer benefits immediately from any improvement or change in data or application or Web service.

The Web service is best written in Java because of the links existing between this language and the language WSDL describing the inputs, outputs and operations of the Web service. Nevertheless, other languages are possible. For example, the companies Meteotest and Meteocontrol have provided services to the prototype by using other languages than Java. MESoR and Task SHC 36 also recommends Eclipse for programming: it is a Open-Source integrated environment for development of applications that permits to test Web services easily. The Web service has then to be deployed on a compliant platform. This platform can be the same than the one selected for the middleware and discussed later.

The Web service is known to the outside by its WSDL, a file that describes the location of the Web service, i. e., its URL, its inputs and outputs, and the operations that can be performed by this Web service. An example is a Web service for converting Fahrenheit degrees into Celsius degrees and conversely. Input may be a series of numbers in float format and output may be series of numbers in the same format. One operation may be the conversion of Fahrenheit into Celsius; another one may be the conversion of Celsius into Fahrenheit. The use of WSDL to expose Web services is a clear advantage to providers as, though emerging, it is a standard on the Web. For example, the GEOSS candidate portals are capable of reading WSDL files and by this way, putting the Web services of a provider on their catalogs. As a consequence, the effort made by a provider to declare a Web service in the prototype can also be exploited without any further effort to disseminate his knowledge on the Web.

To help providers, Task SHC 36 has written a tutorial for developing a Web service and deploying it for its operation on the Web[8]. At the moment of writing, the prototype contains services provided by the DLR from Germany, the companies Meteocontrol from Germany and Meteotest from Switzerland, the Joint Research Center from the European Commission, and MINES ParisTech/Armines from France.

An user interface has been designed, including the API (application programming interface) of Google Maps. Users can therefore use the full capabilities (geographical search, maps and images) of Google to identify their sites and select the right locations or regions. As this interface is easy to use and applied already in many other applications, the user is likely to be familiar with it. The front page of a service gives the site selection window and some descriptive information of the service, as a general description, property rights, credits, inputs and outputs descriptions and benchmark procedure results if relevant. The results can be written to the browser window or saved in a specific format (e.g. spreadsheet-compatible). The available services can be selected by the menu on top of the page.

Next section details the use of the information system by the users.

8 http://www.webservice-energy.org/resources/Web_Service_How-To_Tutorial_v1.1.tar

The prototype is built on freely available software: JBoss platform and Liferay portal. No technology was specifically developed for this prototype, contrary to the initial plan: it was not foreseen that all technologies would be available for free at a mature level. These technologies can be exploited by a commercially-based collaborative information system, without any doubt. The JBoss platform deals with the exchange of messages between the various applications and the Web; it exploits the current standards such as HTTP and SOAP. It also deals with security. The portal Liferay permits to define roles, e.g., customers or managers, and to allocate attributes and rights to each role. Static pages can be defined; a database can be exploited that contains the profile of each customer.

In the previous sections, we have described the role and tools for providers (Web services). Customers access the collaborative information system by a standard browser, e.g., Microsoft Internet Explorer. We have mentioned the basis tools on which the system is built: JBoss and Liferay. We describe now the tools that permit effectively to a customer to invoke a specific Web service. This is the part "Service Invoke Component" in the left part in Figure 2.

For these tools, MESoR and Task SHC 36 have opted for portlets, which are self-contained applications that can be deployed in a portal such as Liferay. Other technologies than portlets could have answered needs as well. For each service, a portlet is developed and deployed. The portlet creates the interface (GUI) to invoke the service, triggers the Web service, listens to the answer, formats it and presents the results to the customer. Figure 11.3 is an example of interface created by the portlet.

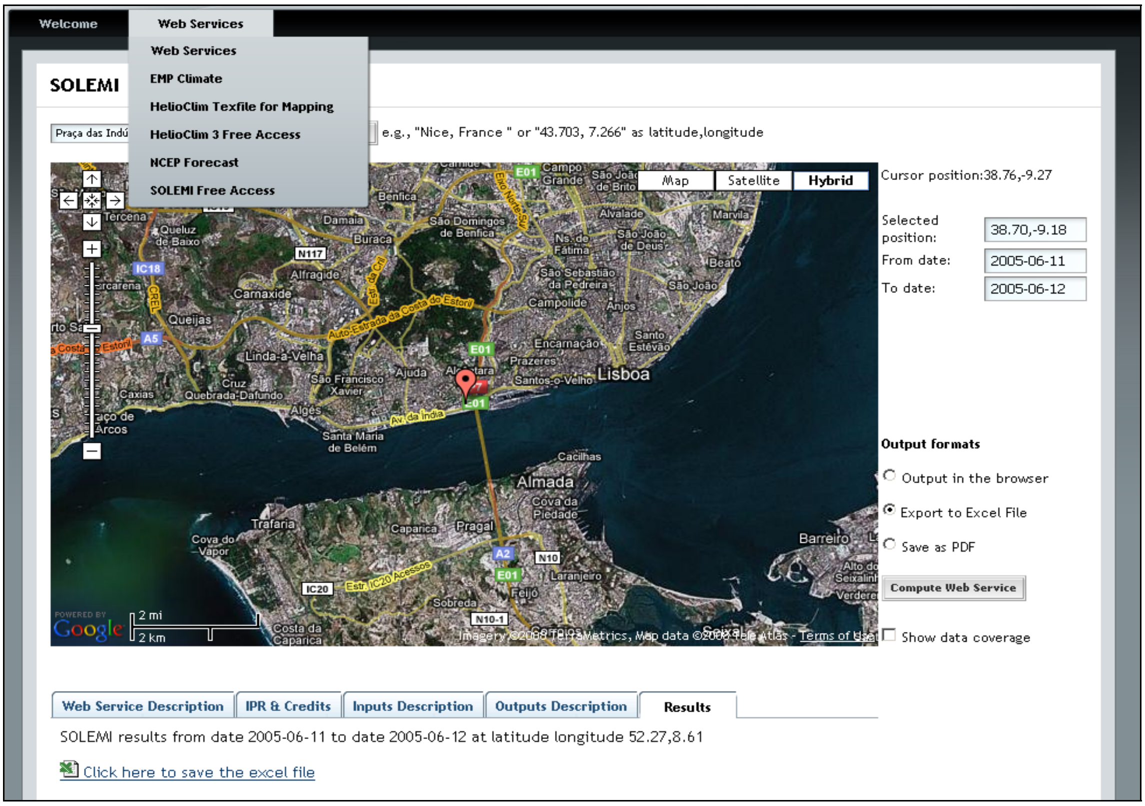


Figure 11.3: Example of the interface created by the portlet for the service "SOLEMI".

The efforts made to cope with standards and guidance of the various international initiatives such as INSPIRE, GEOSS, and OGC, must be underlined. The benefits are worth the efforts (Stackhouse et al. 2006). The interoperability of the information system is consistent and has been proven: the various elements (WSDL, portlet, thesaurus) are in line with these initiatives. From the point of view of the users, interoperability means that the information system has a large capability of retrieving data from various sources. These sources may include public sources which are already disseminating data on the Web in a form that is not that delivered by the prototype system to its users. Due to the interoperability capabilities, the prototype information system may exploit such data for the benefit of its users. An example of such a capability is provided in next section.

This is the role of the broker to develop portlets. To help brokers, Task SHC 36 has written a tutorial for developing a portlet and deploying it for its operation within a Liferay portal. All portlets in the prototype were created in Java but other languages are possible. We have mentioned that Web services may be exploited by several portals at the will of their owners; on the opposite, portlets, and more generally service-invoke components, are dedicated to a portal. They are created by a broker with specific objectives, specific audience and customers. They are the signature of the portal; as they are the interface of the system to the broker, their acceptation by customers is very important for the sustainability of the system.

It follows that given the same set of Web services, two brokers may create two different information systems, both having their own audience and market.

11.4. Using the prototype of the information system

Users can access data and applications at the following URL: http://project.mesor.net/. The following screen will appear (Figure 11.4):

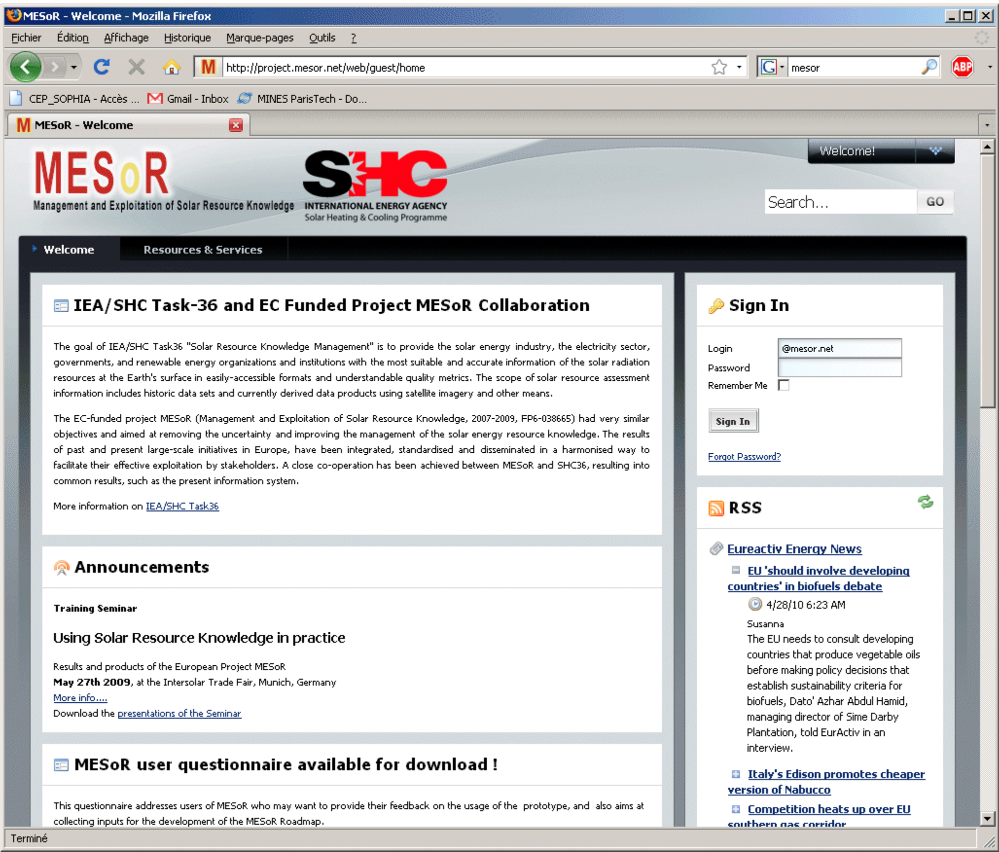


Figure 11.4: Screenshot of the welcome page of the SHC 36 information system

Data and applications are found when passing the mouse on the item "Resources & Services" (Figure 11.5).

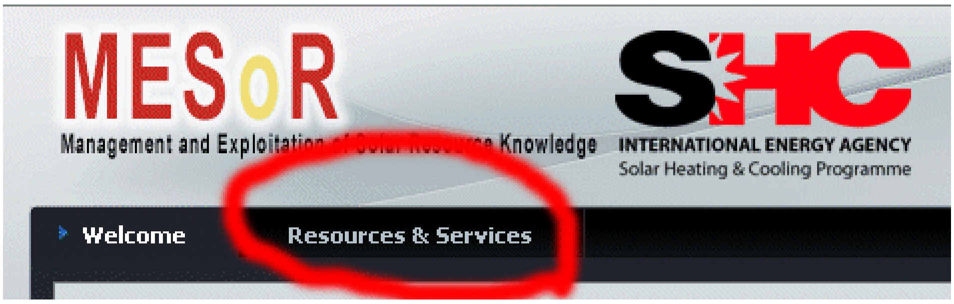


Figure 11.5: Where to find the list of resources and services

Then, a list of services appears and one selects one database or one application. The graphical user interface is more or less the same for all services. Only details change. An example of this interface is shown below, for the service "EMP Climate" (Figure 11.6).

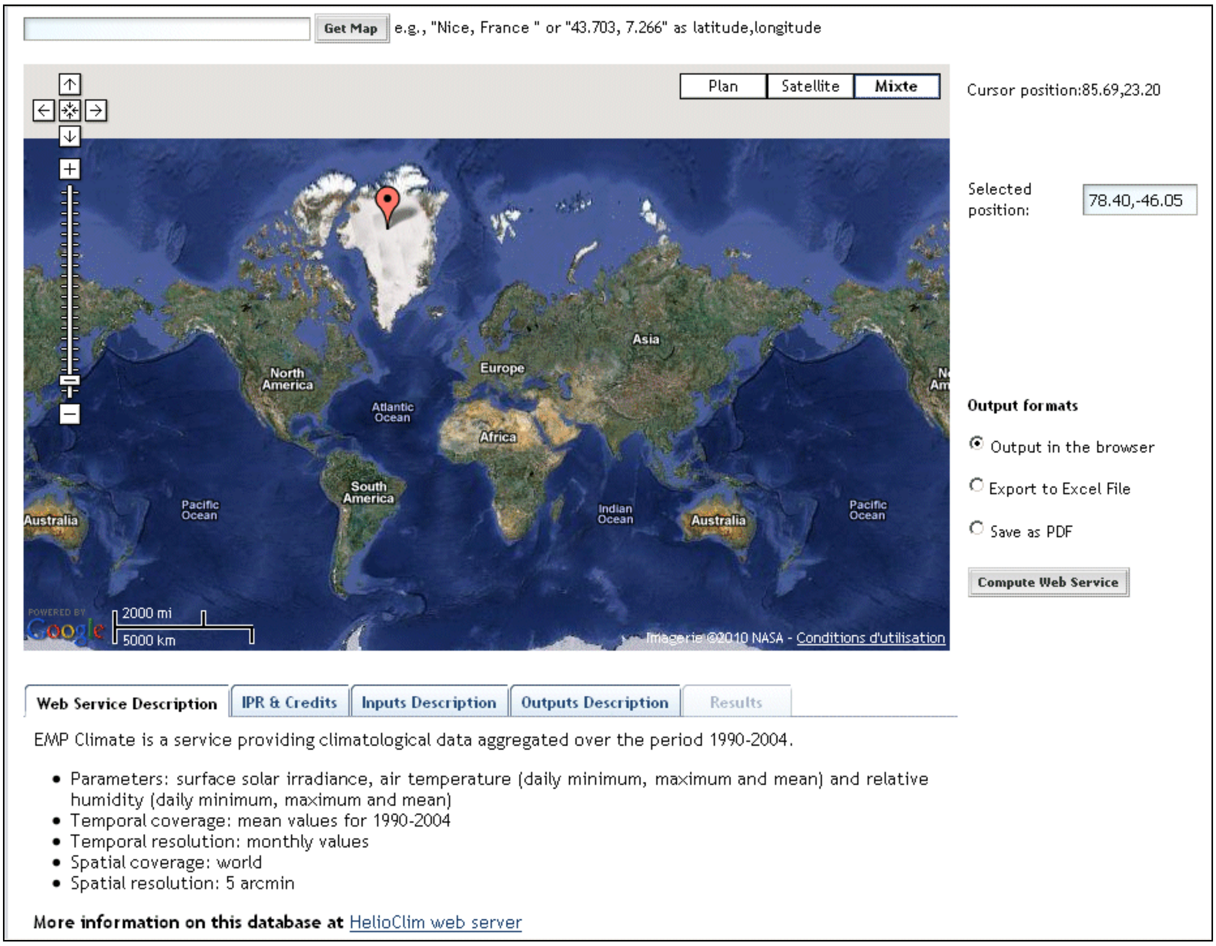


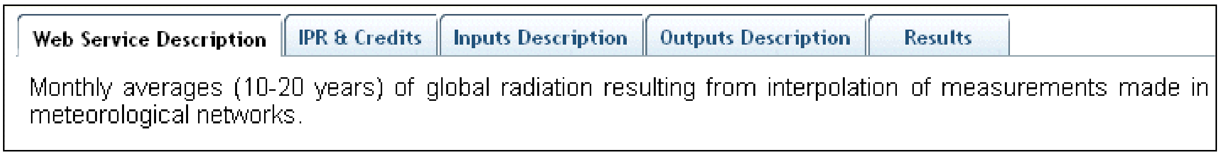
Figure 11.6: Example of the graphical user interface. Service "EMP Climate"

The main part of the interface is occupied by the tool for the selection of the geographical location of interest, or in some cases the geographical area of interest. The Web Portal has adopted the Google interface as it is efficient and well-known to Web users. In the upper left, is a box where users can enter a name of a city or other known locations, or geographical coordinates, in decimal or sexagesimal form, with latitude first. Standard is that from ISO, i.e., latitudes are positive in the Northern hemisphere, and longitudes are positive East of the longitude 0.

Several output formats of results are available: display in the browser, Excel file, or PDF file. The selection of the format is done on the right part of the interface.

Below the map for geographical selection, are several tabs. The fist one provides a short description of the service, with possible links to other servers for more detailed description as in the example above for "EMP Climate" (Figure 11.6) or in the following (Figure 11.7). The second tab "IPR & Credits" details the intellectual and property rights attached to this service and its outcomes. The third "Inputs Description" and fourth tab "Outputs Description" describe the inputs that are necessary to execute the service and the outputs of the service. The fifth tab "Results" contains the results.

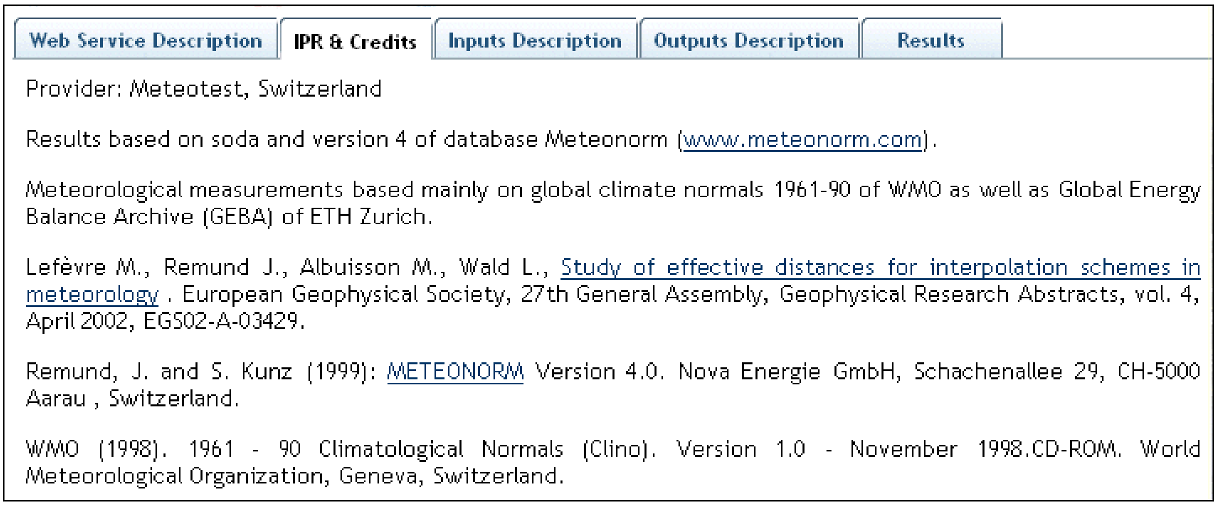
Examples of these tabs are given in Figure 11.7.



Web Service Description | IPR & Credits | Inputs Description | Outputs Description | Results

Monthly averages (10-20 years) of global radiation resulting from interpolation of measurements made in meteorological networks.

Figure 11.7a: Screenshot of the content of the tab "Web Service Description". Example for the service "Meteonorm"



Web Service Description | IPR & Credits | Inputs Description | Outputs Description | Results

Provider: Meteotest, Switzerland

Results based on soda and version 4 of database Meteonorm (www.meteonorm.com).

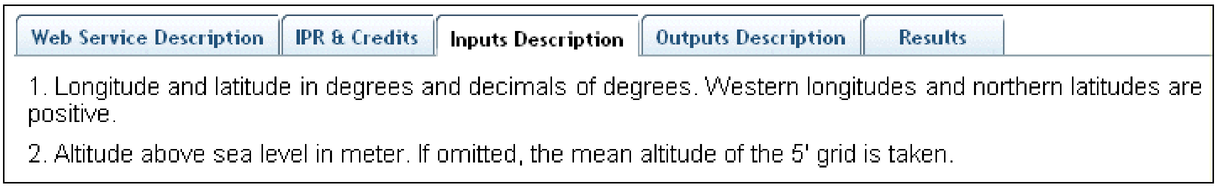
Meteorological measurements based mainly on global climate normals 1961-90 of WMO as well as Global Energy Balance Archive (GEBA) of ETH Zurich.

Lefèvre M., Remund J., Albuisson M., Wald L., Study of effective distances for interpolation schemes in meteorology . European Geophysical Society, 27th General Assembly, Geophysical Research Abstracts, vol. 4, April 2002, EGS02-A-03429.

Remund, J. and S. Kunz (1999): METEONORM Version 4.0. Nova Energie GmbH, Schachenallee 29, CH-5000 Aarau , Switzerland.

WMO (1998). 1961 - 90 Climatological Normals (Clino). Version 1.0 - November 1998.CD-ROM. World Meteorological Organization, Geneva, Switzerland.

Figure 11.7b: Screenshot of the content of the tab "IPR & Credits". Example for the service "Meteonorm"



Web Service Description | IPR & Credits | Inputs Description | Outputs Description | Results

1. Longitude and latitude in degrees and decimals of degrees. Western longitudes and northern latitudes are positive.
2. Altitude above sea level in meter. If omitted, the mean altitude of the 5' grid is taken.

Figure 11.7c: Screenshot of the content of the tab "Inputs Description". Example for the service "Meteonorm"

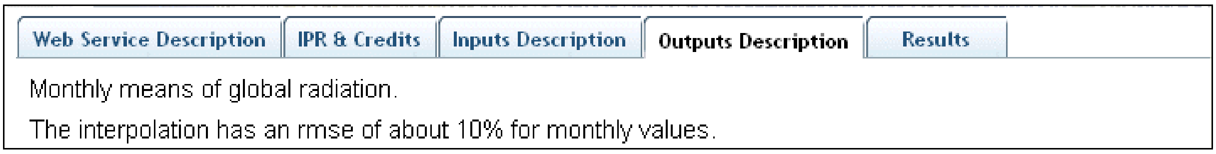
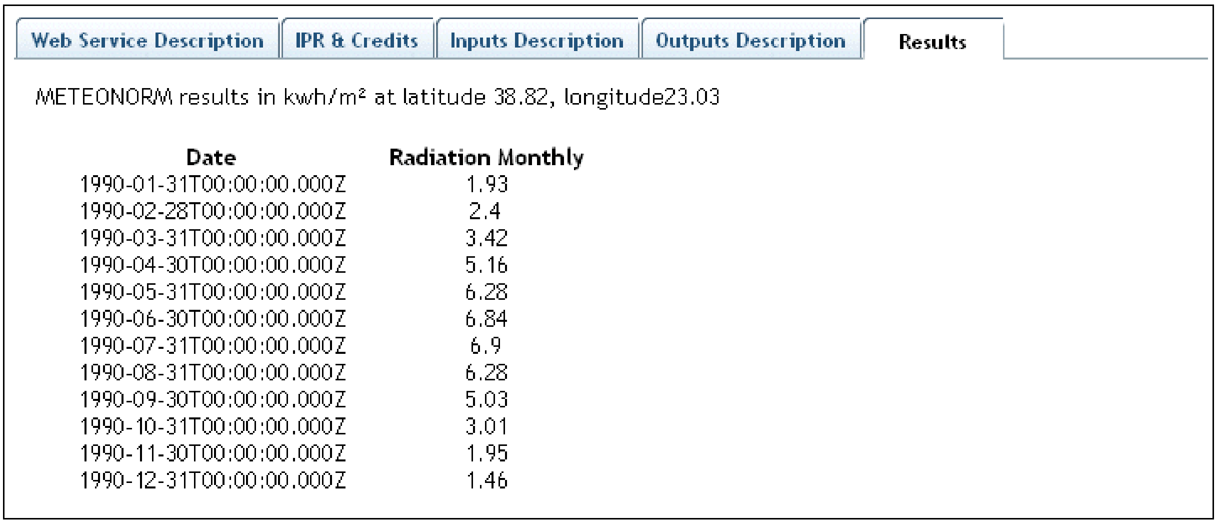


Figure 11.7d: Screenshot of the content of the tab "Outputs Description". Example for the service "Meteonorm"

Once the inputs provided, the service is executed by clicking on the button on the right "Compute Web Service". The results are then displayed in the tab "Results". If the selected output format is "Output in the browser", then, the data will be displayed on the screen, as in Figure 11.8a. If the selected output format is "Export to Excel File", then the tab "Results" will display a link to the Excel file that can be saved on the user's computer (Figure 11.8b).



Date	Radiation Monthly
1990-01-31T00:00:00.000Z	1.93
1990-02-28T00:00:00.000Z	2.4
1990-03-31T00:00:00.000Z	3.42
1990-04-30T00:00:00.000Z	5.16
1990-05-31T00:00:00.000Z	6.28
1990-06-30T00:00:00.000Z	6.84
1990-07-31T00:00:00.000Z	6.9
1990-08-31T00:00:00.000Z	6.28
1990-09-30T00:00:00.000Z	5.03
1990-10-31T00:00:00.000Z	3.01
1990-11-30T00:00:00.000Z	1.95
1990-12-31T00:00:00.000Z	1.46

Figure 11.8a: Example of results, for selected output format "Output in the browser". Example of "Meteonorm"

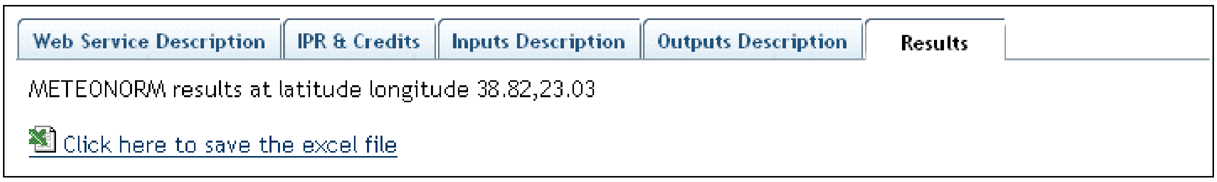


Figure 11.8b: Example of results, for selected output format "Export to Excel File". Example of "Meteonorm"

11.5. Conclusion

These few examples of use of the prototype of the information system demonstrate that the new SoDa Service due to end 2010, offers a solid and consistent framework for the practical dissemination of the MACC-RAD products.

The future MACC-RAD Service can be built on this new SoDa Service. It has several advantages. As the new SoDa Service will meet the GEOSS standards for cataloguing, discovery and exploitation of products, the compliance of the MACC-RAD Service will be easy, with few efforts and effective. Furthermore, the MACC-RAD Service will immediately benefit from the notoriety of the SoDa Service and its large number of users.

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